Wave Spectra in Canadian Waters

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by

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ABSTRACT

LeBlond, P.H., S.M. Calisal, and M. Isaacson. 1982. Wave spectra in Canadian waters. Can. Contract. Rep. Hydrogr. Ocean Sci. 6:57 p. + 134 p. Appendices.

This report addresses topics concerning the specification and description of wave spectra in Canadian waters. Modern requirements for spectral wave information are reviewed: the form of one-dimensional spectra now provided by MEDS is found to be generally satisfactory; directional spectral information is finding increasing use in design and is presently lacking in Canadian wave climatology.

A limited set of one-dimensional wave spectra observed in a variety of Canadian marine environments is compared to three parametric spectra: the Pierson-Moskowitz, the Scott and the JONSWAP spectra. Although the JONSWAP spectrum provides the overall best fit to individual spectra, the "peak enhancement parameter" which matches its height to the observed spectral peak shows so much scatter that it is not possible to recommend the JONSWAP in preference to the Scott spectrum for design purposes. The Pierson-Moskowitz spectrum provides an adequate fit to observations only in a small number of samples, corresponding to fully developed seas.

Specific recommendations are presented for the development of a Canadian spectral wave climatology, based on the analysis of information now available and on methods of processing data to be collected in the future.

RÉSUMÉ

LeBlond, P.H., S.M. Calisal, and M. Isaacson. 1982. Wave spectra in Canadian waters. Can. Contract. Rep. Hydrogr. Ocean Sci. 6:57 p. + 134 p. Appendices.

Le présent rapport traite des questions relatives aux caractéristiques et à la description des spectres de vagues dans les eaux canadiennes. Les besoins actuels en matière de données spectrales sur les vagues sont passés en revue: on estime que le type de spectres unidimensionnels fourni par le SDMM est généralement satisfaisant; les données spectrales directionnelles sont de plus en plus utilisées pour la conception et sont actuellement insuffisantes dans le cadre de la climatologie des vagues au Canada.

Une série limitée de spectres de vagues unidimensionnels observés dans divers milieux marins au Canada est comparée à trois spectres paramétriques: les spectres Pierson-Moskowitz, Scott et JONSWAP. Dans l'ensemble, c'est le spectre JONSWAP qui s'adapte le mieux aux spectres de la série, mais le facteur de rehaussement de pointe, que fait correspondre sa hauteur à la pointe du spectre observée, présente tant de dispersion qu'il n'est pas possible de recommander le JONSWAP de préférence au Scott pour la conception. Le spectre Pierson-Moskowitz ne s'adapte correctement que pour un petit nombre d'échantillons, qui correspondent à une mer forte stabilisée.

Des recommandations précises sont formulées pour l'élaboration d'une climatologie spectrale des vagues au Canada, à partir de l'analyse des données recueillies, et à l'aide de méthodes de traitement des données à collecter à l'avenir.

COMMENTS BY THE SCIENTIFIC AUTHORITY

This report was prepared by Seaconsult Marine Research in two steps. Initially, the contract called for the preparation of a specialist report for design requirements for fixed and floating structures from two recognized authorities to define the spectral fitting to be carried out. After reviewing the results of the fitting, the specialists were asked to extend their report to include a review and comments on the findings of the study. Their report is included here as Appendix II.

The second comment has to do with the low frequency energy present in spectral plots 13 and 25. The low frequency energy is not real. It is probably the result of brief interruptions of the telemetry circuit by radio interference. The records were left in the file because it was judged that the value of significant wave height and peak period were not substantially altered by this noise; i.e., the peak period was representative and the area under the spectrum was not seriously affected (5%) by the noise. In retrospect, the records are marginal and possibly should have been deleted from the file.

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1. INTRODUCTION

The scope and sophistication of both coastal and offshore structures have increased rapidly over the past decades, keeping in step with man's ever more ambitious plans to master the sea and extract its resources. The quality and the quantity of environmental information required for the conduct of safe and profitable operations at sea have attempted to keep pace with the higher demands made on men and materials; however, for engineering design purposes, the analysis, parameterization and presentation of those collected data require reassessment.

This report addresses an important aspect of the offshore wave climate, namely the specification of spectral characteristics of waves. Spectral wave information needs are identified in Chapter 2 on the basis of a literature survey, recent conference proceedings and the advice of recognized experts. A discussion of the parametric representation of spectra, together with a preliminary study of the fit of commonly used spectral curves (Scott, Pierson-Moskowitz, and JONSWAP) to spectra obtained in Canadian waters, are presented in Chapter 3. Methods of presentation of spectral wave information are reviewed in Chapter 4. Our conclusions and recommendations are presented in Chapter 5.

2. WAVE INFORMATION

2.1 General Design Considerations

This chapter briefly reviews modern requirements for spectral wave information in the design of coastal and offshore structures and vessels. The assessment of modern needs has been compiled from recent literature and conference proceedings, as quoted in the text, and with the help of Profs. M. Isaacson and S. Cališal, respectively of the Departments of Civil and Mechanical Engineering at the University of British Columbia. These persons are recognized authorities on structural design and naval architecture. The results of the Wave Information Workshop held at the Bedford Institute of Oceanography in October 1980 (Mason, 1982) have also guided the study.

The nature of wave information deemed necessary for proper design of marine structures and vessels has evolved rapidly over the past decades, as the size and complexity of structures have increased and the methods of structural analysis have become more sophisticated. As noted by Ploeg and Funke (1982), the confidence of designers has been severely shaken by their realization of the importance of hitherto neglected or unsuspected wave effects. Whereas in the 1950's and 1960's manuals were written with a certain level of confidence in the techniques of design subject to wave loading, modern texts (e.g. Sarpkaya and Isaacson, 1981) are much more qualified, especially with respect to the behaviour of deep water structures.

Estimates of fluid loading due to wave motion on fixed and floating structures are required for three broad purposes: assessment of survivability, normal operational considerations and fatigue calculations.

The term survivability, refers to the ability of a structure to survive the wide range and combinations of environmental conditions to which it may be subjected. This concept includes an assessment of the structure's response to extreme conditions, such as 100-year waves, but it extends also to a broader range of conditions, involving the joint effects of less-than-extreme loadings by a combination of different forces. In this respect, the high end of normal wave events is of relevance to survivability estimation because, although such sea-states may be well below the design wave height level of a structure, their occurrence simultaneously with other events (for example, high winds, or human error) may lead to catastrophic consequences.

Normal operational considerations are concerned with the behaviour of a structure and with the activities carried out on and around it on a day-to-day basis. Estimates of downtime under certain sea-states and directions, or of possible damage to peripheral appendages of a structure require some knowledge of normal wave conditions on a monthly or seasonal basis.

Fatigue is the cummulative effect of a succession of stress fluctuations on the elements of a structure. Fatigue may lead to failure even under weak loading after a long time and is the crucial factor in determining the operational lifetime of a structure.

2.2 Spectral Wave Information Requirements

Because marine vessels and structures are complex mechanical systems their response to applied forces is generally frequency-dependent. It is thus necessary to specify wave forces as a function of frequency in order to study their effect on a marine structure. Frequency-dependent wave information is most commonly extracted from wave data and used by the design engineer in the form of a power spectrum: a smoothed plot of the distribution of sea-level variance as a function of frequency (and possibly also direction of propagation). The power spectrum does not contain all the frequency information available in the original data: a complementary phase spectrum represents the statistics of the relative phase between waves of different frequencies. Nevertheless the power spectrum has become a universally used method of representing wave conditions and finds widespread application in calculations of structural response and fatigue.

The use of spectral methods in structural loading calculations has been reviewed by Sarpkaya and Isaacson (1981). Current concerns in the application of spectral techniques include a recognition of the influence of low frequency effects, often parameterized under the term "groupiness", on the response of large structures, be they floating (Roberts, 1981) or stationary (Johnson et al., 1978), as well as the importance of the high frequency tail of the spectrum which is directly linked to stress reversals and fatigue related problems. The main effort in this study is focussed on simplifying observed wave spectra in terms of an analytical curve which preserves the features of the observed spectra that are important for engineering analysis. We shall return to this problem of spectral parameterization at length below.

Waves are specified in terms of their direction of propagation as well as of their frequency. Two dimensional spectra, showing the distribution of variance in terms of frequency and direction are often necessary in ship and structural design. Dalzell (1974), Cox and Lloyd (1977), Hoffman and Chen (1978), and Berge (1981) have discussed the need for directional spectra. Large and complex marine structures, such as floating bridges (Langen and Sigbjörnsson, 1981), as well as naval requirements for wave information, as for wave power research (Crabb, 1981), require directional wave information. The study of the response of long structures also requires information on the relation between simultaneous sea-level displacements at two locations (Webster and Trudell, 1981) in terms of a cross-spectrum between these locations, a function related to directional spectral quantities.

The current engineering requirements for wave spectral information as reviewed by Hogben (1974, 1980) within the framework of the activities of ECOR (The Engineering Committee on Oceanic Resources) have been incorporated with the additional advice of Profs. Calisal and Isaacson in the following summary.

Spectral Requirements

1) Discrete spectra:
   * Density of sea-level variance in the range 0 - 1 Hz with a 0.01 Hz bandwidth interval.
   * Directional information in 12 directions (i.e. every 30°) for each frequency band.

2) Parametric spectra:
   * In most practical cases, it is sufficient to describe the sea-state in terms of a parametric spectrum.

   A parametric spectrum must be simple, i.e. depend on a small number of parameters, and be well founded in observations: the type of spectrum chosen as well as the values of parameters used must provide a good fit to the average spectrum observed at the location and over the time period of interest.

The rest of this report focuses on the question of the need for parametric spectra, the methods of fitting such spectra to data with an application to Canadian waters, and means of presenting parametric spectral wave information.

2.3 Parametric Spectra

The body of discrete spectral information collected from direct wave observations is difficult to apply to engineering studies for a number of reasons. First of all, information collected over a period long enough to ensure statistical representativeness would yield so many spectra that it would be impossible to try to use them all: they have to be averaged, by season or type. These observed spectra would also show a large degree of variability, based in part on natural variations and in part on statistical fluctuations. There is obviously a need for a synthesis of observational spectra. The parametric spectrum represents such a synthesis: an analytical function dependent on frequency and direction of propagation which includes a small number of physically meaningful parameters.

Many parametric curves of the form S(f), where S is the energy per unit bandwidth and f the frequency, have been proposed over the years for the one-dimensional (non-directional) spectrum; among the best known are those of Darbyshire (1952), Neumann (1953), Bretschneider (1959), Pierson and Moskowitz (1964), Scott (1965), Mitsuyasu (1973), and Hasselmann et al. (1973). More complicated spectral representations include the six-parameter curve of Ochi and Hubble (1976), which attempts to model the spectral peak and the high frequencies separately, and the polynomial fit of Gospodnetic and Miles (1974), which represents the spectrum in terms of a power series in significant wave height and period with frequency dependent coefficients.

Two-dimensional parametric spectra include, in addition to a function specifying the energy density in terms of frequency, a directional spreading factor about the mean wave direction. Borgman (1979) has discussed various parameterizations of the directional wave spectrum S(f,θ) in terms of a product of frequency (f) and angle (θ) dependent factors:

$$S(f,\theta) = S(f)D(f,\theta). \tag{2.1}$$

A commonly used spreading function $D(f,\theta)$ is the "cosine-squared" function

$$D(f,\theta) = G(s)\cos^{2s}\left(\frac{\theta-\theta_o}{2}\right) \quad , \tag{2.2}$$

where the parameter s specifies the spread in angle θ of the wave energy about a central direction θ_o (usually the wind direction). The factor G(s) is a normalizing function.

The parameter s has been found empirically (Mitsuyasu et al., 1975; Hasselmann et al., 1980, Hogben, 1981) to vary with wave frequency, taking a maximum value of about 10 -- corresponding to a very narrow beam -- at the frequency where S(f) has its peak value. The directional spectral parameterization expressed by (2.1) and (2.2) would then contain only one directional parameter, θ_o, since s is a function of frequency.

Further discussion will be concerned with fitting of one-dimensional spectra only. Although the techniques of fitting of spreading functions to observed directional spectra, as explained by Borgman (1979), Long (1980) and Van Heteren and Keyser (1981), are generally more complicated than those used in fitting one-dimensional spectra, many of the restrictions and caveats discussed below carry over to two-dimensional spectral fitting.

3. PARAMETRIC FITTING OF OBSERVED SPECTRA

3.1 Description of Parametric Spectra

Although all one-dimensional parametric spectra have some features in common, they differ in their precise shape and in the number and nature of their fitting parameters. It is clearly important to choose a parametric spectrum which combines simplicity with a good fit to observed conditions to provide a spectral climatology in an area. For this preliminary assessment of the fit of parametric curves to observed spectra in Canadian waters three of the simpler and best known curves, the Pierson-Moskowitz (1964), Scott (1965) and JONSWAP (Hasselmann et al., 1973) spectra, have been examined. These curves have been widely used in engineering and oceanographic applications.

3.1.1 The Scott Spectrum

The Scott (1965) spectrum is based on a modification of an earlier spectrum of Darbyshire (1952). The spectral energy density is given by

$$S_1(f) = \begin{cases} 1.34H_s^2 \exp - \left[\dfrac{(f-f_o)^2}{0.01(f-f_o+0.042)} \right]^{\frac{1}{2}} \\ \qquad\qquad \text{for } -0.041 < f-f_o < 0.26 \\ 0, \text{ outside that range.} \end{cases} \qquad (3.1)$$

$S_1(f)$ is the variance of sea-surface displacement in m^2/Hz; f is the frequency (Hz) and f_o the frequency of the peak energy of the spectrum; H_s is the significant wave height in meters. Here, as elsewhere, H_s is defined as

$$H_s = 4\sqrt{m_o} \qquad (3.2)$$

where m_o is the zeroth moment of the spectrum, i.e. the area under the curve S(f):

$$m_o = \int_o^\infty S(f)\, df \qquad (3.3)$$

The Scott spectrum is completely specified by two parameters: the spectral peak frequency f_o and the significant wave height H_s.

This spectrum has been found to give a good fit to observations in the Persian Gulf, the North Atlantic and on the west coast of India (Dattatri et al., 1977; Chakrabarti and Cooley, 1978). The Scott spectrum is very similar in shape, if not in functional form, to the Mitsuyasu (1973) spectrum; it is shown in Figure 3.1 in a form normalized by H_s^2

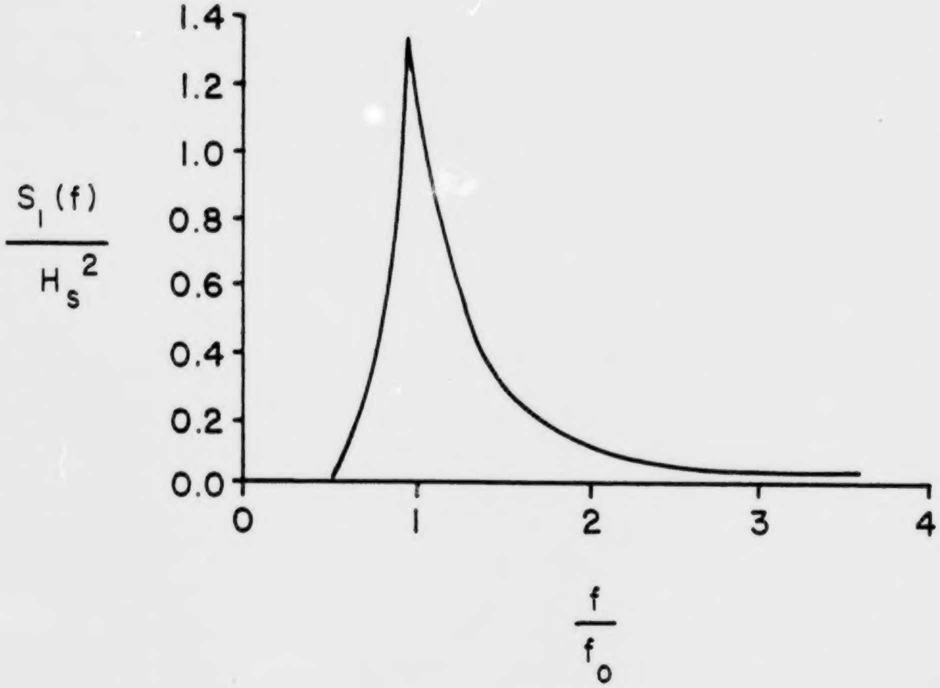

Figure 3.1. The Scott spectrum, for f_o = 0.1 Hz.

3.1.2 The Pierson-Moskowitz Spectrum

The Pierson-Moskowitz (1964) spectrum is based on a refinement of the Bretschneider (1959) spectrum. The spectral energy density is given by

$$S_2(f) = \frac{A}{f^5} \exp\,(-B/f^4), \tag{3.4}$$

In the absence of wind speed data, the A and B coefficients are expressed in terms of the spectral peak frequency f_o and significant wave height H_s (Bretschneider, 1959) as

$$A = 5\,H_s^2 f_o^4/16 \quad ; \quad B = 5f_o^4/4 \tag{3.5}$$

Like the Scott spectrum, it includes only the two parameters H_s and f_o. The functional form (3.4) also encompasses the ITTC (International Towing Tank Conference) spectrum (Hogben, 1980). A non-dimensionalized form of (3.4) is plotted in Figure 3.2.

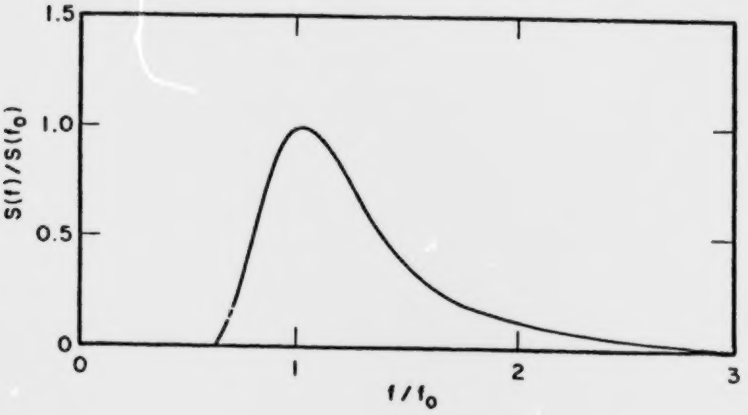

Figure 3.2. The Pierson-Moskowitz spectrum.

3.1.3 The JONSWAP Spectrum

Curve fitting by Hasselmann et al. (1973) to spectra observed during the Joint North Sea Wave Program (JONSWAP) suggested that fetch-limited waves would be better fitted by modifying the Pierson-Moskowitz spectrum in the form

$$S_3(f) = \frac{A}{f^5} \exp\left(-B/f^4\right)\gamma^a \qquad (3.6)$$

where γ is the peak enhancement factor. We will use the form introduced by Hasselmann et al. (1973) for the exponent a:

$$a = \exp\left[-(f-f_o)^2/2\sigma^2 f_o^2\right] . \qquad (3.7)$$

The peak frequency factor σ was found by Hasselmann et al. (1973) to be independent of fetch, with the values

$$\begin{aligned} \sigma &= 0.07 \qquad f \leq f_o \\ &= 0.09 \qquad f > f_o \end{aligned}$$

There are then only three parameters left for fitting: A, B and γ. The availability of an additional parameter makes it likely that a better fit would be achieved. Many observed spectra have been sucessfully approximated by the JONSWAP curve particularly in growing seas and in fetch-limited areas (Houmb et al., 1974; Houmb and Overvik, 1976; Rye and Svee, 1976; Mitsuyasu et al., 1980; Kahma, 1981). The spectral form (3.6) is shown in Figure 3.3.

The parameter B remains as defined in (3.5) in terms of peak frequency but, because of the presence of the enchancement factor γ, the relation between A and H_s is more complicated. For $1<\gamma<4$, which includes most values encountered, Mitsuyasu et al. (1980) have calculated that

$$A \simeq 5H_s^2 f_o^4/16\gamma^{1/3} \qquad (3.8)$$

We will use this result throughout, although we will find that some (about 15%) of the estimated values of γ will be larger than 4.

Using (3.8), we can then identify H_s, f_o, and γ as the three free parameters of the fitted JONSWAP spectra.

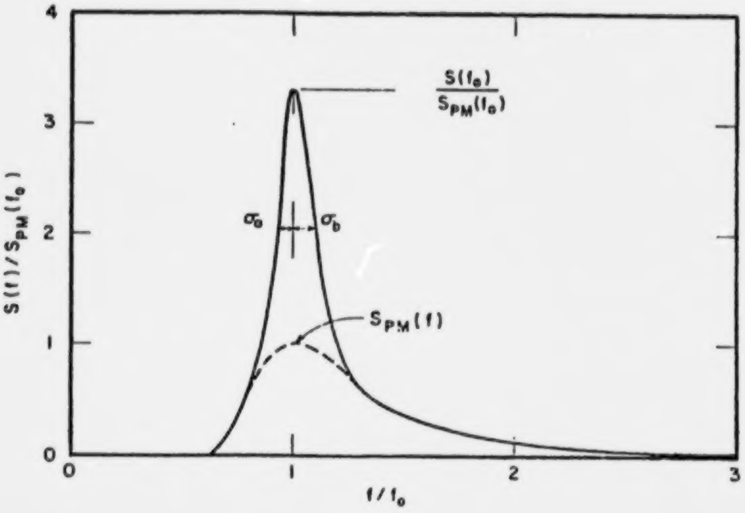

Figure 3.3. The JONSWAP spectrum (solid curve) compared to the Pierson-Moskowitz spectrum $S_{PM}(f)$. Note that the two spectra correspond to different values of H_s: γ is not the ratio of the Pierson-Moskowitz to JONSWAP spectral peak heights for the same total variance.

3.3 Normalized Spectra

As the fetch and the wind speed increase, waves grow and their peak frequency decreases. Experimentally, the wave energy increases very nearly linearly with fetch, while the peak period increases as the 1/3 power of the fetch, Hasselmann et al. (1973). Successive spectra in a developing sea-state will thus differ in H_s (increasing) and f_o (decreasing). In order to compare successive spectra and to assess the relative fit of different spectral forms, it is convenient to normalize the spectra so that differences in peak height (via H_s) and frequency (f_o) do not mask more fundamental differences.

Non-dimensional Scott, P.M. and JONSWAP spectra are defined by the normalizing relation

$$S^*(f) = f_o S(f)/H_s^2 \tag{3.9}$$

Thus,

$$\text{Scott:} \quad S_1^*(f) = 1.34\ f_o \exp\left\{-\left[\frac{(f-f_o)^2}{0.01(f-f_o+0.042)}\right]^{\frac{1}{2}}\right\} \tag{3.10}$$

$$\text{P.M.:} \quad S_2^*(f) = \frac{5}{16}\left(\frac{f}{f_o}\right)^{-5} \exp\left[-\frac{5}{4}\left(\frac{f_o}{f}\right)^4\right] \tag{3.11}$$

$$\text{JONSWAP:} \quad S_3^*(f) = \frac{5}{16\gamma^{1/3}}\left(\frac{f}{f_o}\right)^{-5} \exp\left[-\frac{5}{4}\left(\frac{f_o}{f}\right)^4\right]\gamma^a \tag{3.12}$$

where a is given in (3.7). The observed discrete spectral values will be normalized in the same fashion.

3.3 Fitting Method

Each one of the observed spectra obtained from MEDS consisted of a sequence of values of energy density $P(f_i)$ at 62 values of the frequency f_i ($i = 1,\ldots 62$) from 0.05 to 0.5 Hz. In each case, the peak frequency f_o was identified as that value of f_i corresponding to the maximum

P, and H_s was found using (3.2) and the relation

$$m_o = \sum_{i=1}^{62} P(f_i)\Delta f_i \tag{3.13}$$

The two parameters f_o and H_s defining the Scott and the P.M. spectra are thus readily found. The parameter necessary to complete the specification of the JONSWAP spectrum is found from matching the height of the observed spectral peak $P(f_o)$ to that of the JONSWAP spectrum:

$$P(f_o) = S_3(f_o) = \frac{5H_s^2}{16f_o} \exp(-\frac{5}{4})\gamma^{2/3} \tag{3.14}$$

from which

$$\gamma = \left\{ P(f_o) \Big/ \frac{5H_s^2}{16f_o} e^{-5/4} \right\}^{3/2} \tag{3.15}$$

Non-dimensional spectra $S_1^* \ldots S_3^*$ are then plotted, together with the observed spectrum (also normalized: $P^* = f_o P/H_s^2$) for visual comparisons. The quality of the fit is characterized by the normalized root-mean-square difference between the model and observed curves; the "goodness of fit" parameter is defined as

$$R_j = \sqrt{\sum_{i=1}^{N} [P^*(f_i) - S_j^*(f_i)]^2} \Bigg/ \sum_{i=1}^{N} P^*(f_i) \tag{3.16}$$

for j = 1,2,3 corresponding to the three parametric spectral forms.

One sequence of graphs of the spectral comparisons is shown in Figures 3.4 - 3.10 for immediate reference and discussion. The complete results of this comparison for a number of Waverider records are presented in Appendix I.

In addition to the spectral comparisons and a table of goodness of fit results, each graph includes a table of spectral parameters calculated from the observations: significant wave height H_s (m), peak period $T_p = 1/f_o$ (sec), peak frequency f_o (Hz), the second moment m_2 (m^2/sec^2), the spectral width parameter ε and the peakedness parameter Q_p. The latter three parameters are defined as

$$m_2 = \sum_{i=1}^{N} f_i^2 P(f_i) \Delta f_i$$

$$\varepsilon = (1 - m_2^2/m_o m_4)^{1/2}$$

$$Q_p = 2 \sum_{i=1}^{N} f_i P^2(f_i) \Delta f_i \Big/ m_o^2$$

with

$$m_4 = \sum_{i=1}^{N} f_i^4 P(f_i) \Delta f_i$$

and N = 62.

Variations of the goodness of fit, of the JONSWAP peak enhancement parameter γ and of other spectral parameters may then be compared to the parameters specifying the sea-state, f_o and H_s, and to each other.

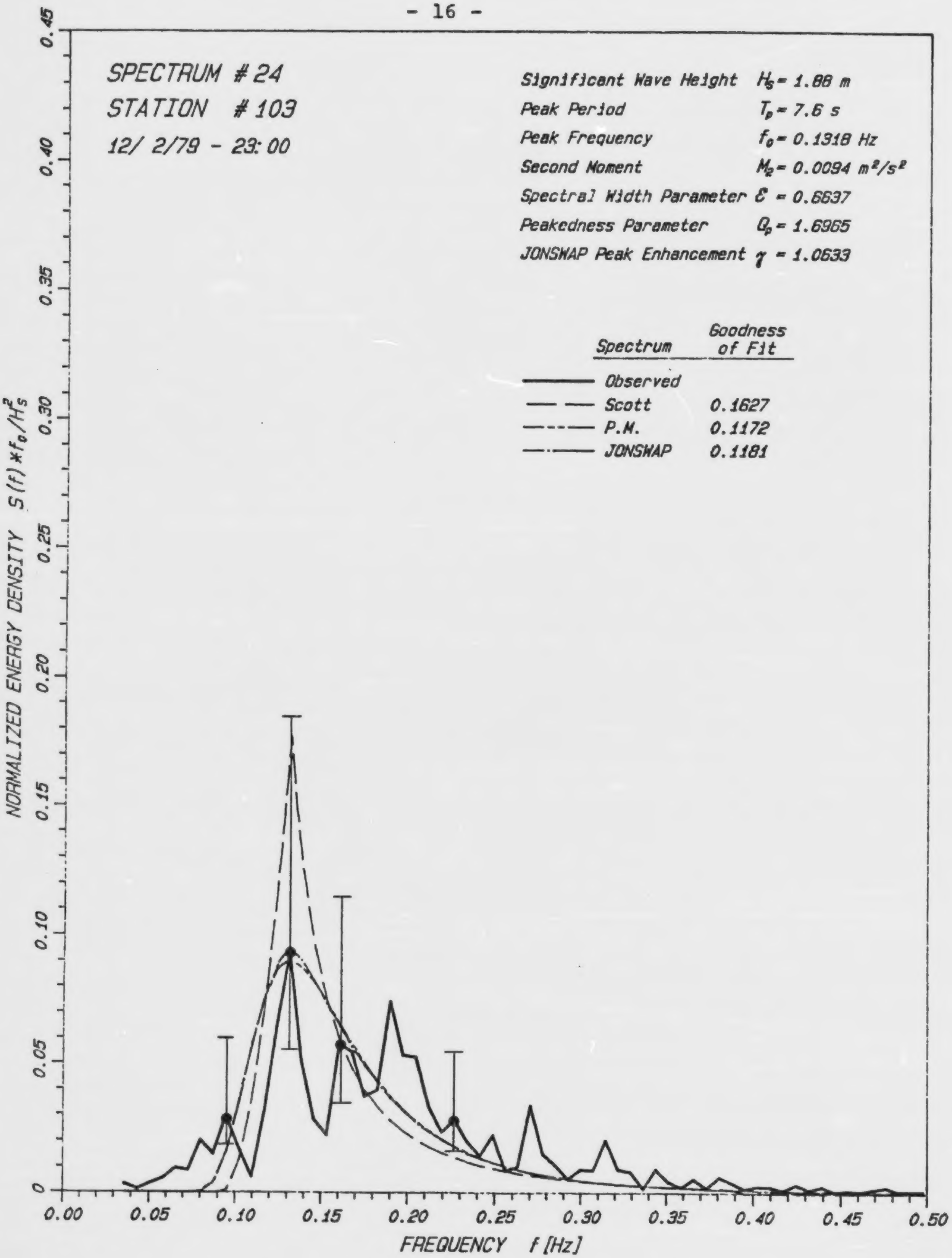

Figure 3.4 Comparison of fitted and observed spectra at Tofino, on the west coast of Vancouver Island.

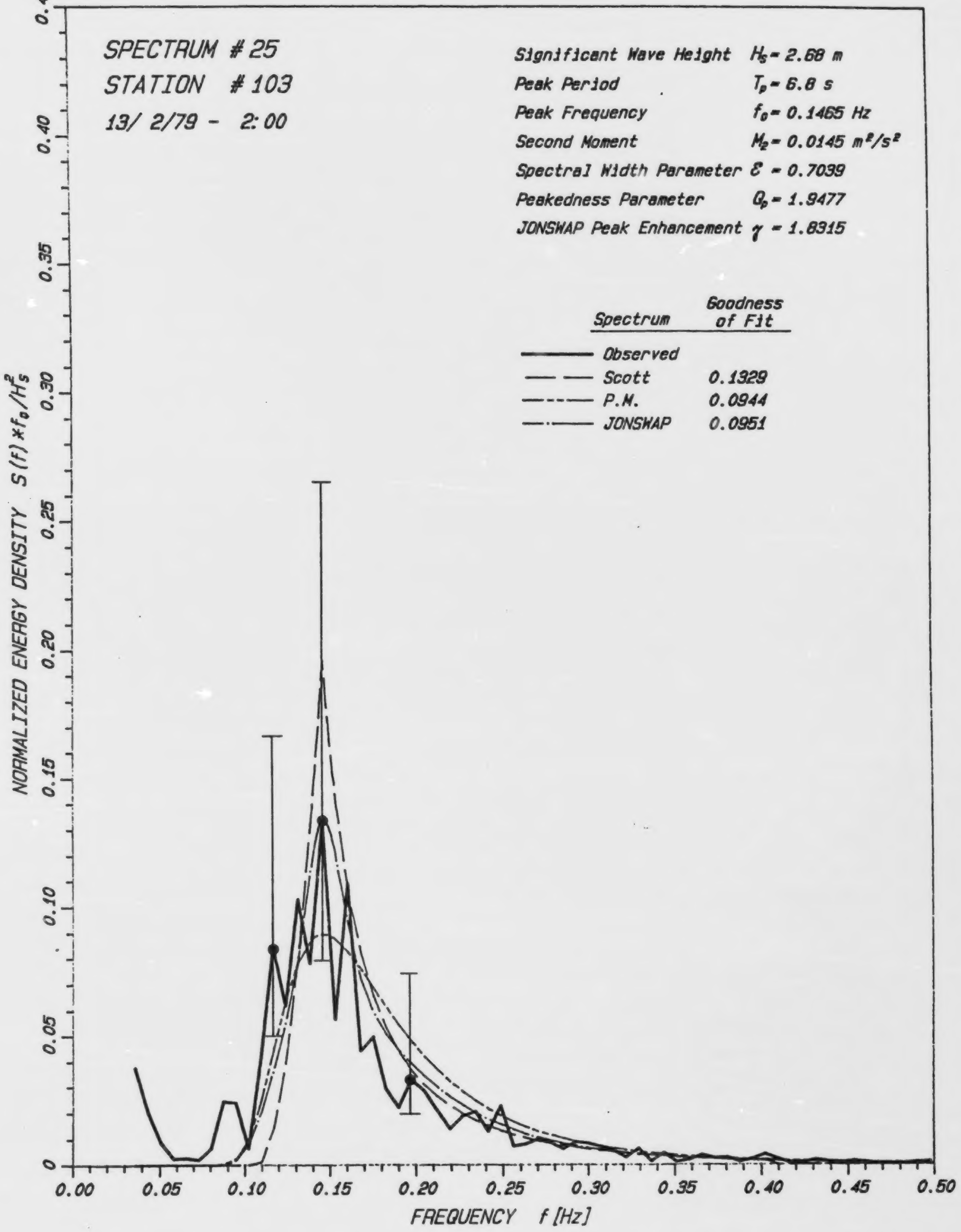

Figure 3.5 Comparison of fitted and observed spectra at Tofino.

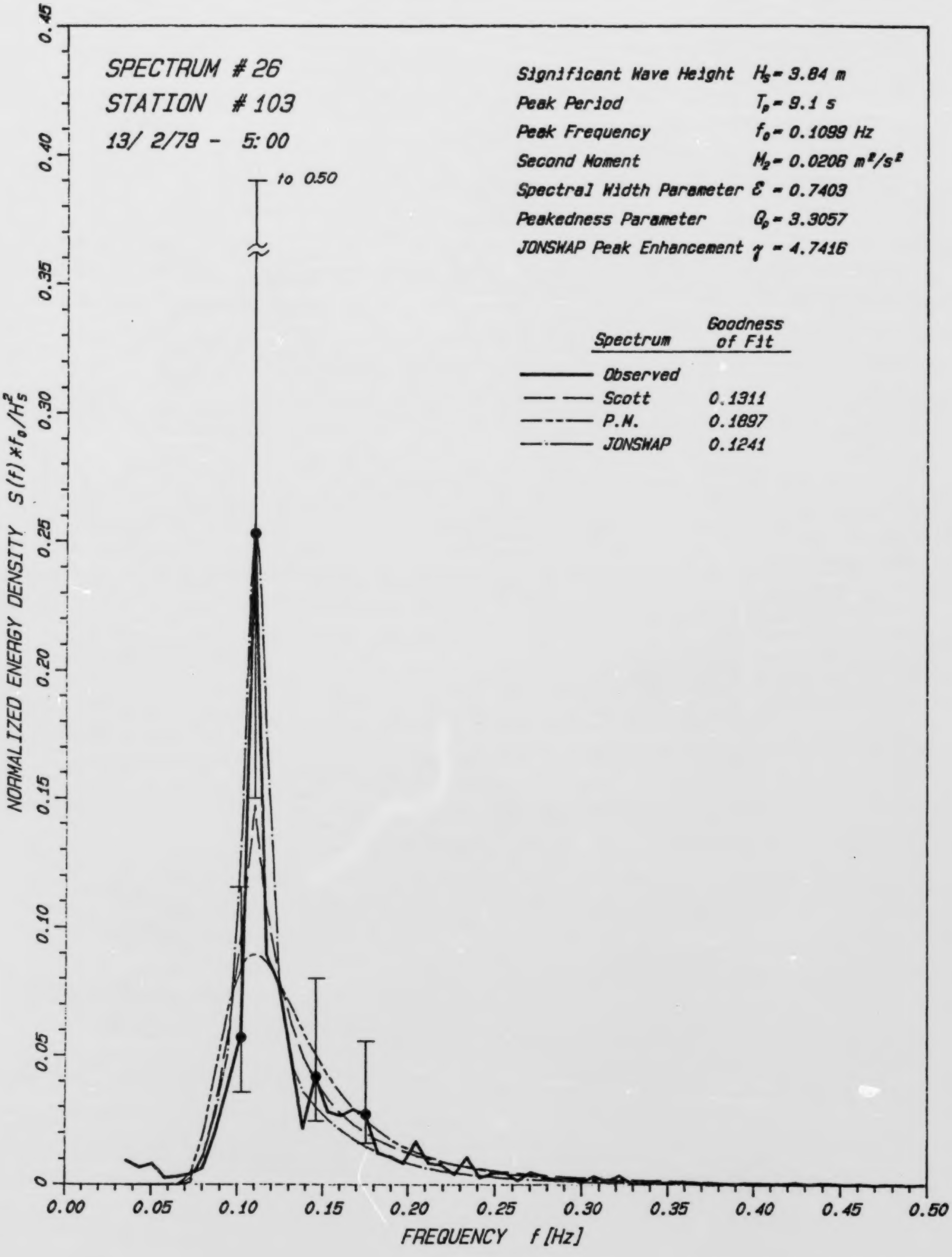

Figure 3.6 Comparison of fitted and observed spectra at Tofino

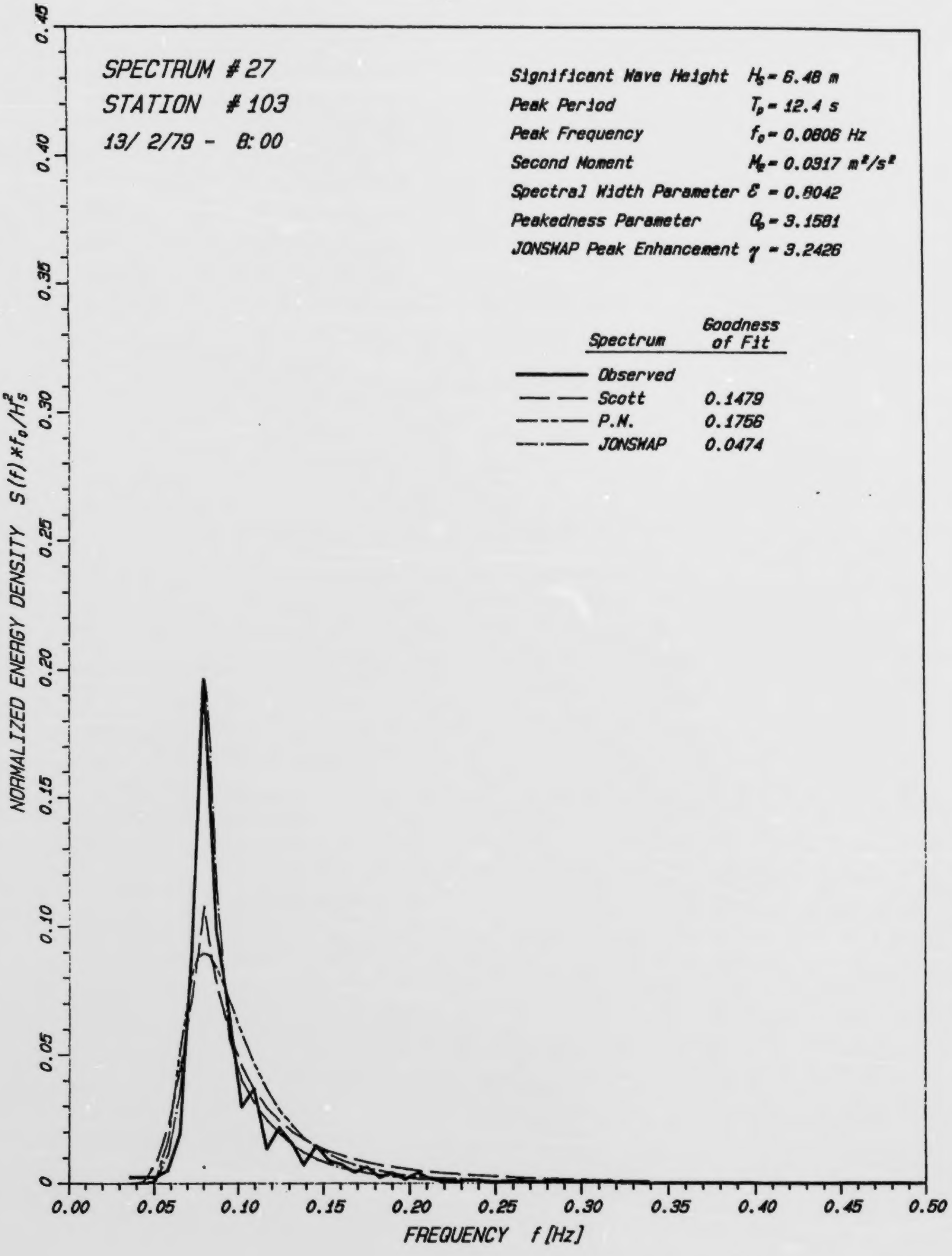

Figure 3.7 Comparison of fitted and observed spectra at Tofino.

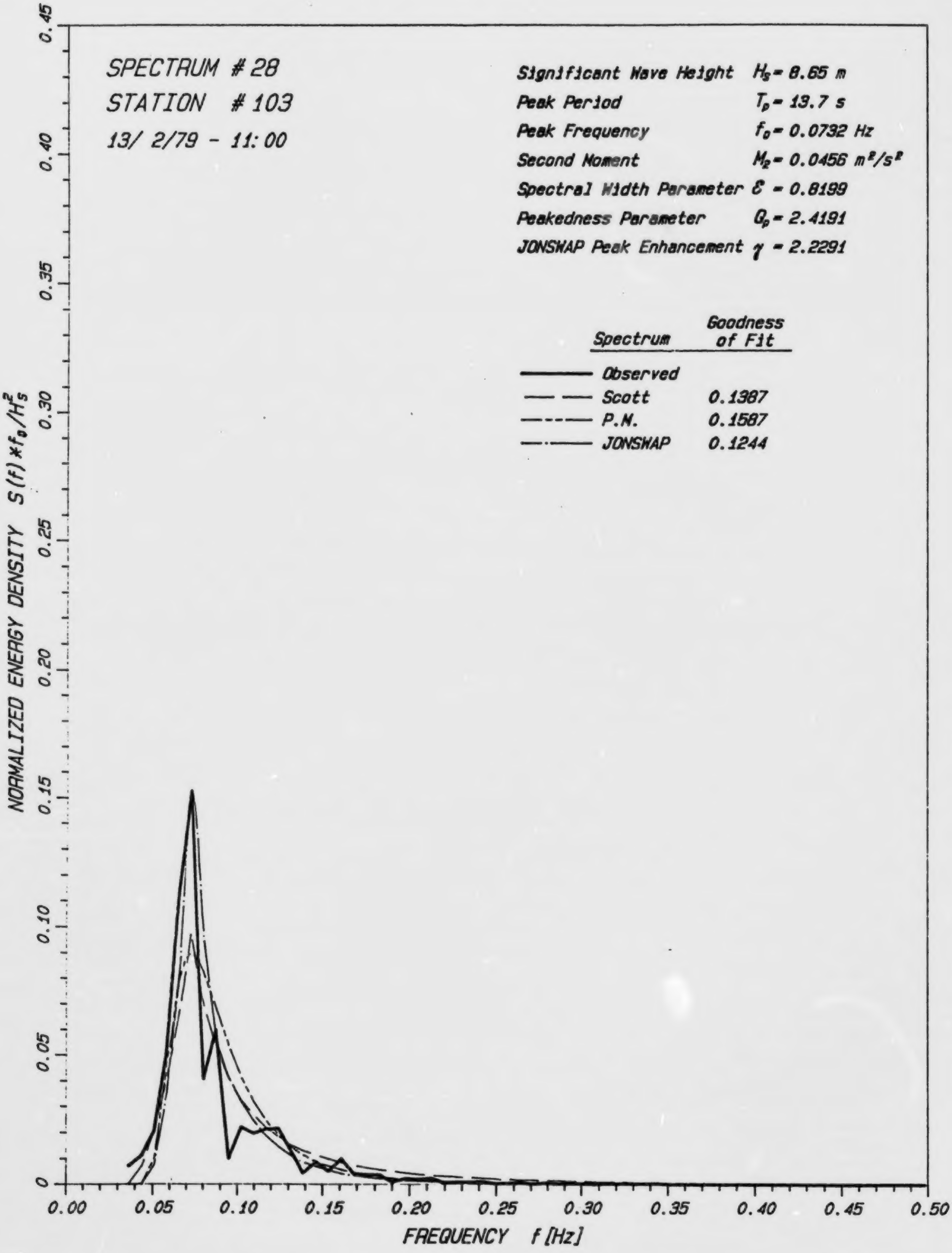

Figure 3.8 Comparison of fitted and observed spectra at Tofino.

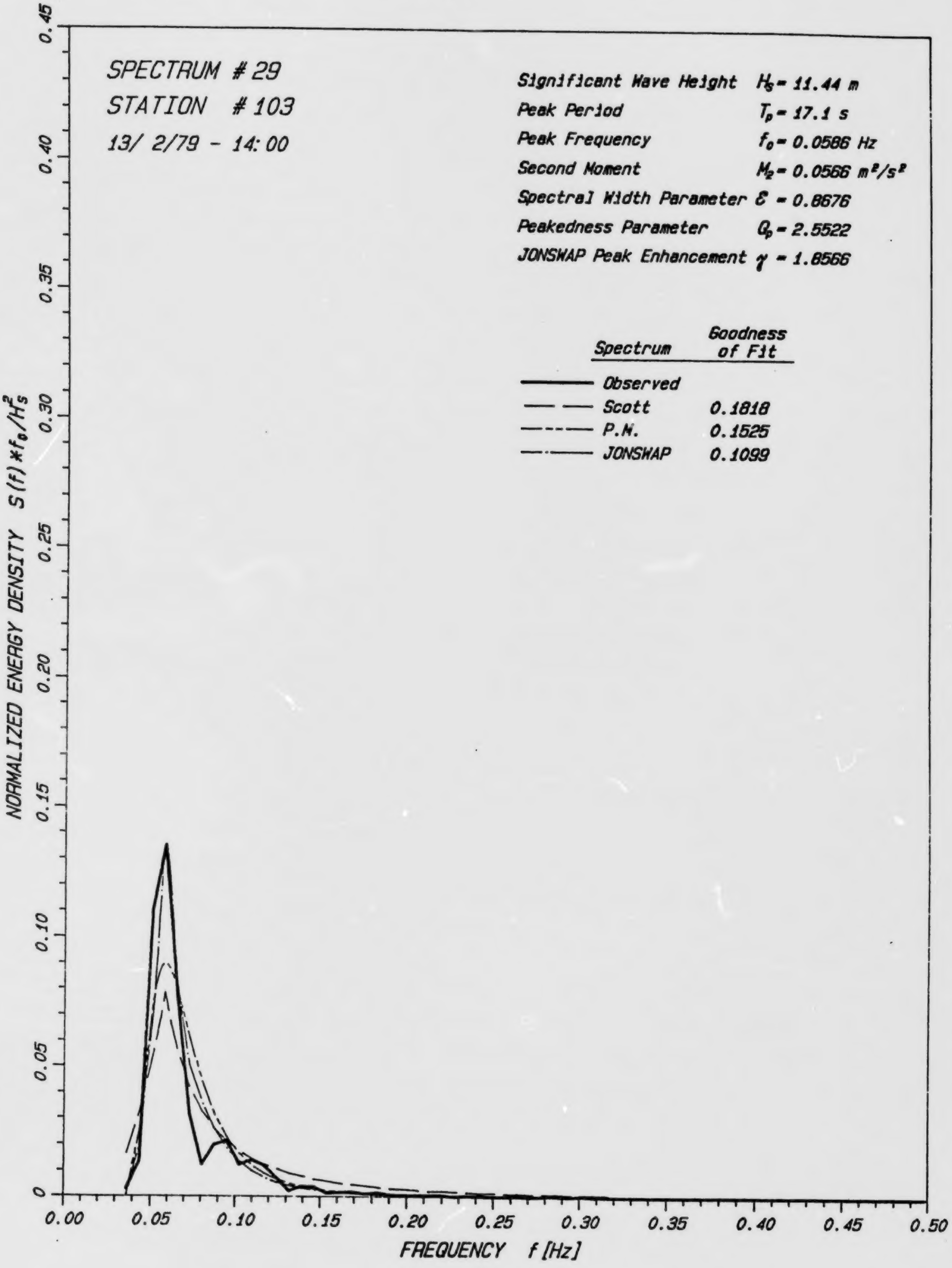

Figure 3.9 Comparison of fitted and observed spectra at Tofino.

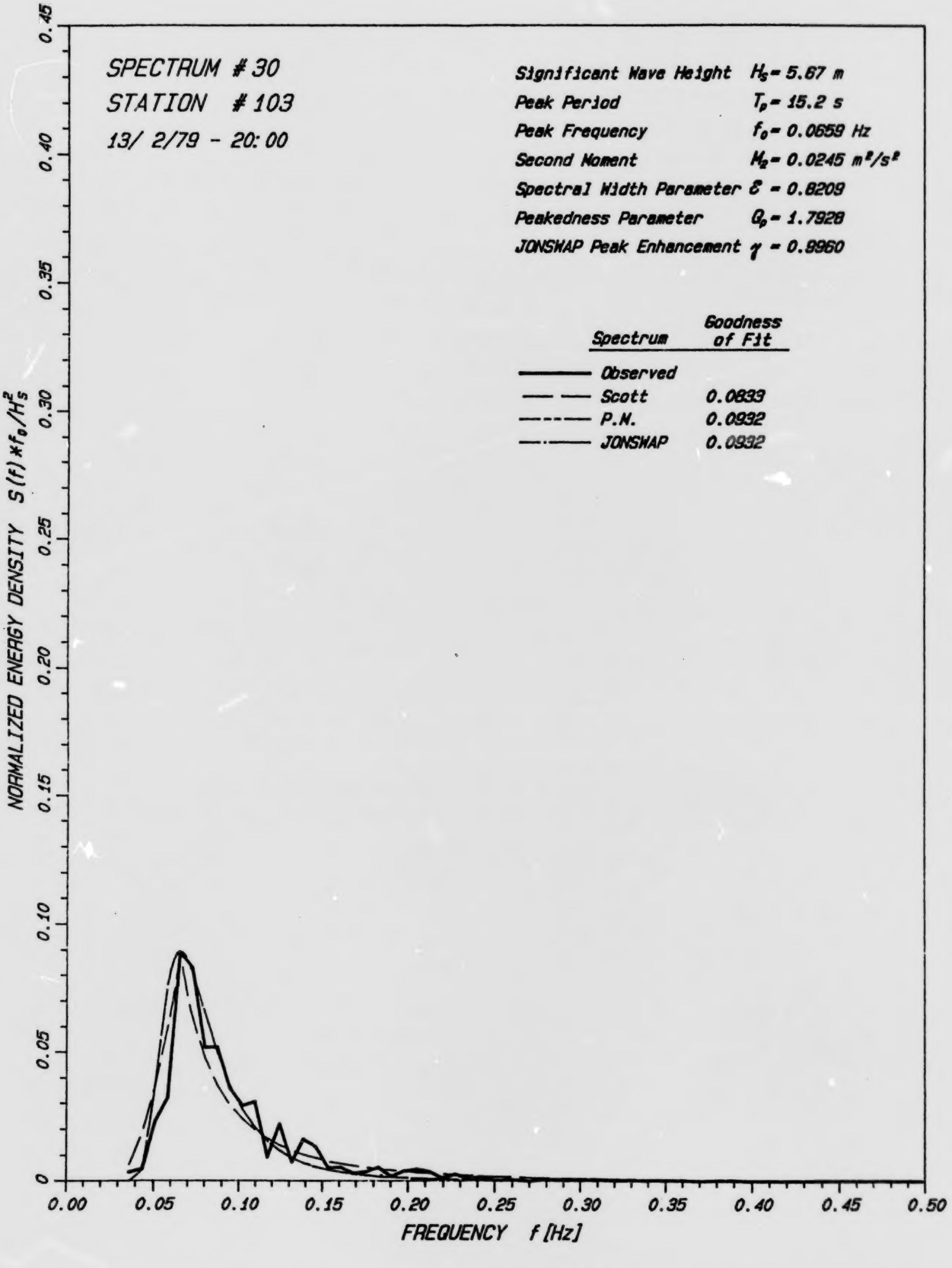

Figure 3.10 Comparison of fitted and observed spectra at Tofino.

3.4 Discussion of Fitted Spectra

The wave measuring stations from which the data were obtained are identified in Table I, together with their location and water depth. The observed spectra, presented in the appendix, provide a small sample of waves over a storm or two at a number of different Canadian marine locations: the Atlantic, the Pacific, the Beaufort Sea and Lake Ontario. There are 112 spectra altogether, taken from 100 different storms.

Each series of spectra shows growing seas, with gradually increasing values of peak period T_p and significant wave height H_s. Figures 3.4 - 3.10 show one typical sequence at Tofino, on the west coast of Vancouver Island. In the first 15 hours, the waves grow, with the significant wave height passing from $H_s = 1.88$ m to 11.44 m and the peak period increasing from $T_p = 7.6$ sec to 17.1 sec. The waves decay following the passage of the storm: after a further 6 hours, H_s and T_p have fallen to 5.67 m and 15.2 sec respectively.

The general relationship between T_p and H_s for all 112 spectra is shown in Figure 3.11. In spite of the fact that the data are drawn from 6 different locations, this diagram shows no more scatter than is usual for such plots for one location. The scatter is however too great to distinguish between fetch limited seas, for which $T_p \propto H_s^{2/3}$, and saturated conditions, where $T_p \propto H_s^{1/2}$. Since the data come from a mix of fetch limited (Lake Ontario) and open ocean areas, one would expect waves of both types. However, in this study meteorological information was not incorporated to relate spectral forms and parameter values to the wind and its fetch and duration.

A visual inspection of the fitted spectra shows some common (but no universal) features:

TABLE I

Station identification and location.

Station #	Spectra #	Name	Area	Location Lat.	Location Long.	Depth (m)	Date D/M/Y
60	1-7	Mainduck Is.	Lake Ontario	43-44-45N	076-49-39W	69	9/ 8/72
"	8-17	"	"	"	"	"	14/11/72
103	18-23	Tofino	Pacific Coast	48-59-27N	125-44-39W	40	15/11/75
"	24-30	"	"	"	"	"	12/ 2/79
138	31-39	Ben Ocean Lancer	Davis Strait	62-11-08N	062-58-17W	360	25/ 7/80
"	40-64	"	"	"	"	"	17/ 9/80
140	65-78	Zapata Ugland	Hibernia	47-03-12N	48-44-48W	95	15/ 1/82
"	79-100	"	"	"	"	"	14/ 2/82
201	101-106	Explorer II	Beaufort Sea	70-34-00N	134-35-00W	61	29/ 8/80
202	107-112	Explorer IV	"	70-49-00N	130-18-00W	58	29/ 8/80

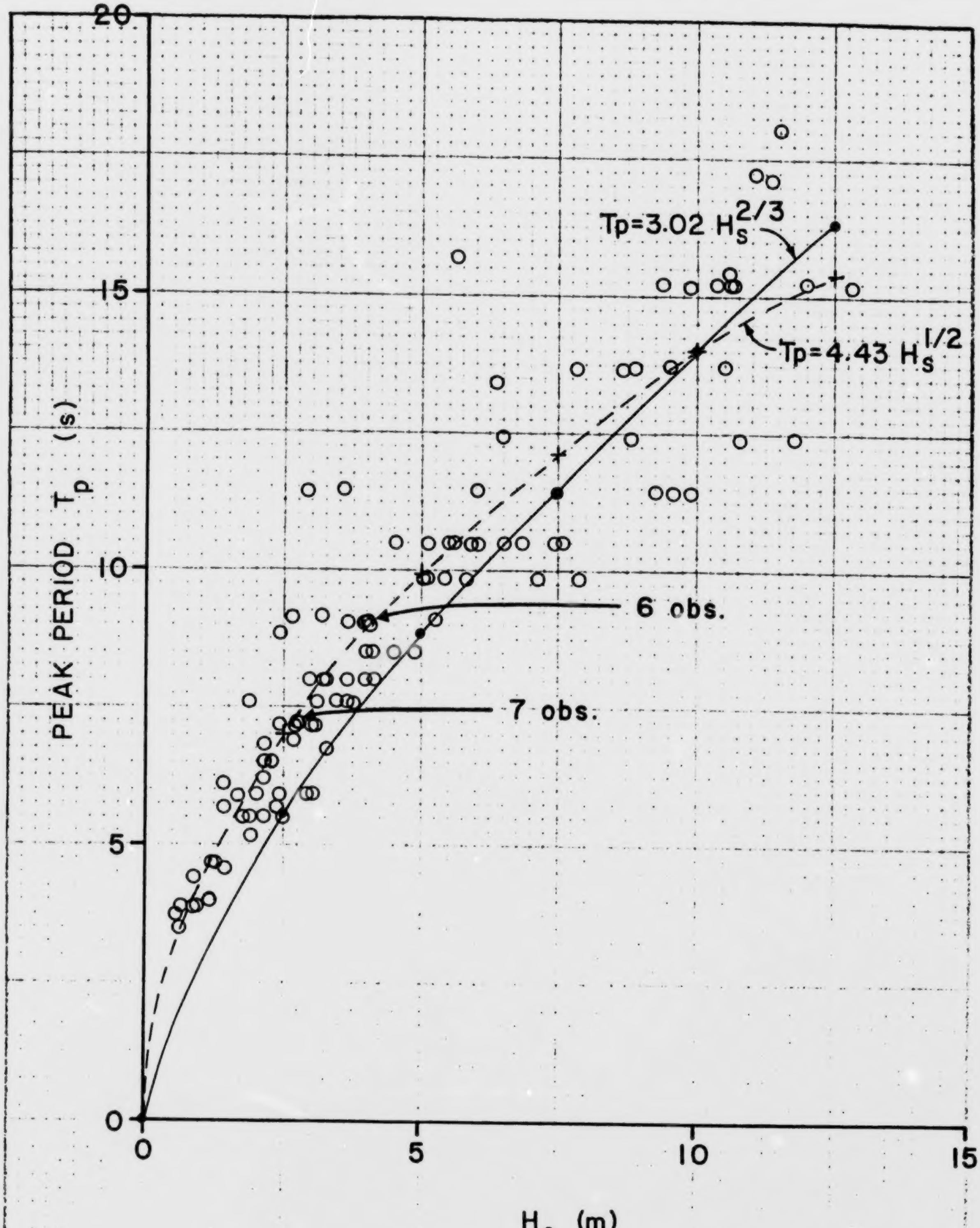

Figure 3.11 Scatter plot of spectral peak period T_p (in seconds) vs significant wave height H_s (in meters) for all spectra.

1) The best fit to the observed spectra, as defined by the closeness of fit near the peak of the spectrum, and in the frequency band just above the peak, for $1.5\ f_o < f < 2.5\ f_o$, is usually provided by the JONSWAP spectrum.
2) The P.M. spectrum usually underestimates the height of the spectral peak, except for the largest sea-states in a given storm. It also often tends to overestimate spectral levels at medium frequencies, between $1.5\ f_o$ and $2.5\ f_o$.
3) The Scott spectrum is often as good as the JONSWAP spectrum in fitting the spectral peak.
4) In general, the type of spectrum which fits best at any one location varies considerably with time -- a result also noted by Thompson (1974).

A quantitative evaluation of the goodness of fit is provided by the calculated values of R_j (as defined by 3.16) for the three parametric curves. The numerical values of R_j are very sensitive to the large differences between fitted curve and observed spectrum which occur near and just above the spectral peak, so that a small value of R_j corresponds to a good visual fit as described above. Scatter diagrams of the actual values of R_j versus H_s are shown in Figures 3.12 - 3.14. The superiority of the JONSWAP spectrum stands out where the ratios of goodness of fit of Scott to JONSWAP (R_1/R_3) and P.M. to JONSWAP (R_2/R_3) are plotted (Figures 3.15, 3.16). These ratios are almost always greater than unity, showing that the JONSWAP spectrum almost always provides a better fit than the other two curves. The distribution of fit ratios is also shown in histogram form in Figure 3.17, restating the result in a different form.

The regional variability of the relative goodness of fit of the parametric spectra and of the values of the peak enhancement factor γ is presented in Table II. There are

TABLE II

Regional distribution of JONSWAP peak enhancement factor γ and relative goodness of fit of Scott & P.M. spectra vs. JONSWAP.

Region	No. of Spectra	$\bar{\gamma}$	γ-Range	Average Scott-JONSWAP Fit	Average P.M./JONSWAP Fit
Lake Ontario	7	3.8	2.5-5.7	1.14	1.33
"	10	4.7	2.7-8.8	0.99	1.70
Pacific Coast	6	2.3	1.0-4.0	1.60	1.77
"	7	2.3	1.0-4.7	1.51	1.55
Labrador Coast	9	3.0	2.2-4.0	1.12	1.83
"	25	3.2	1.9-5.2	1.13	1.68
Grand Banks	14	2.2	0.9-4.1	1.42	1.58
"	22	2.2	1.1-4.7	1.53	1.70
Beaufort Sea	6	2.2	1.4-3.7	1.33	0.95
"	6	2.2	1.7-2.7	1.32	1.06

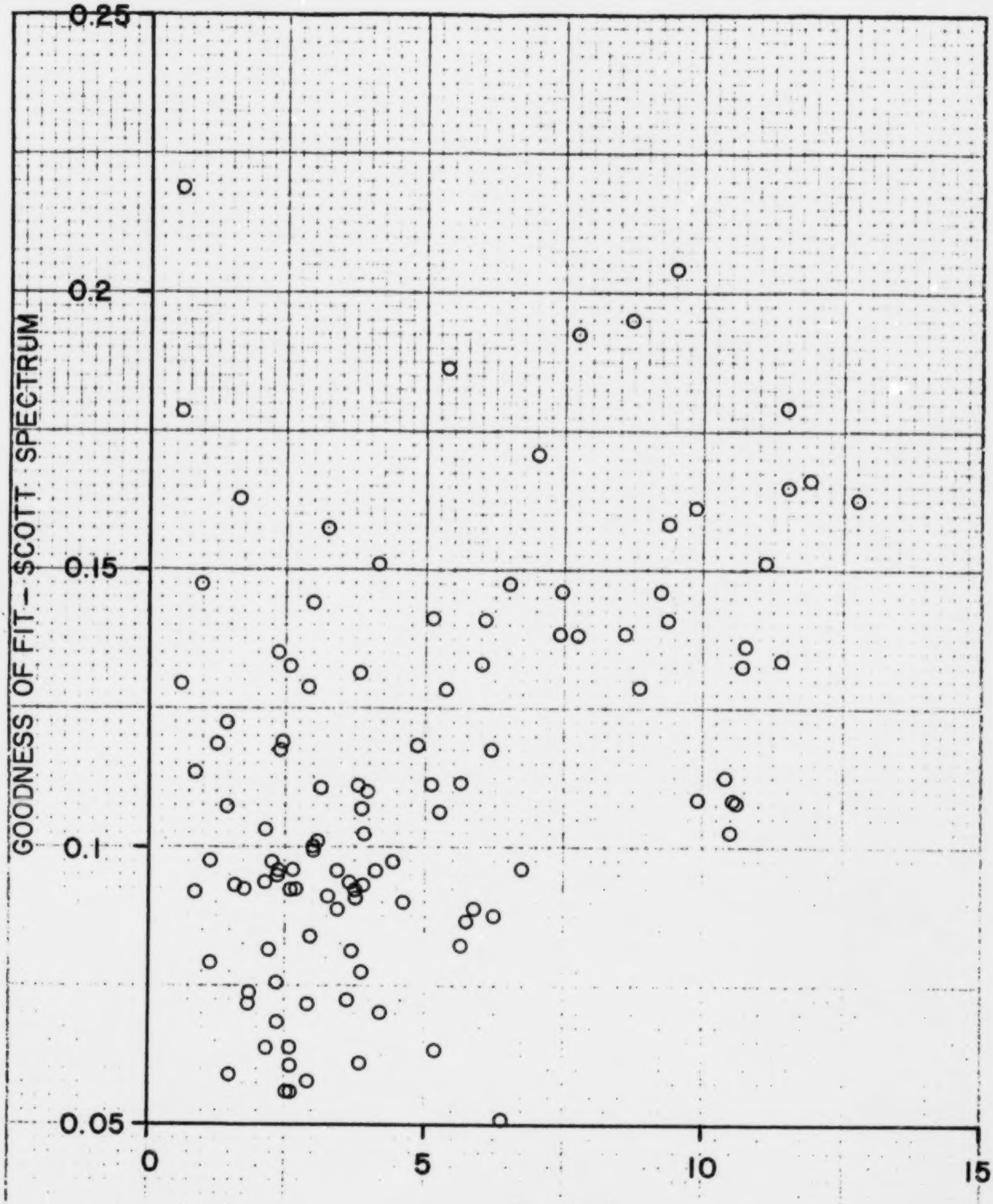

Figure 3.12 Goodness of fit of the Scott spectrum to observed spectra as a function of significant wave height H_s. Small values indicate good fit.

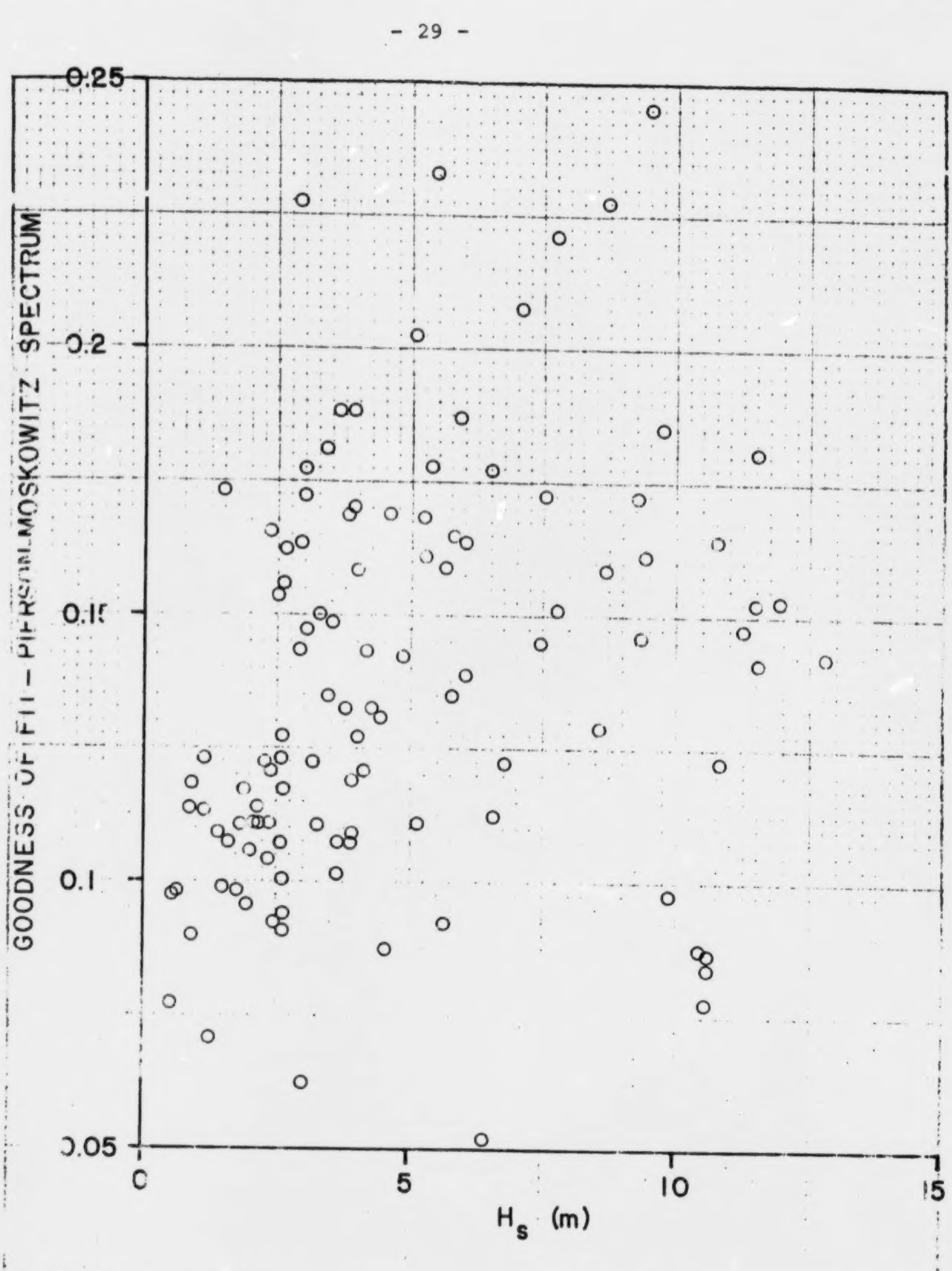

Figure 3.13 Goodness of fit of the Pierson-Moskowitz spectrum to observed spectra as a function of significant wave height H_s. Small values indicate good fit.

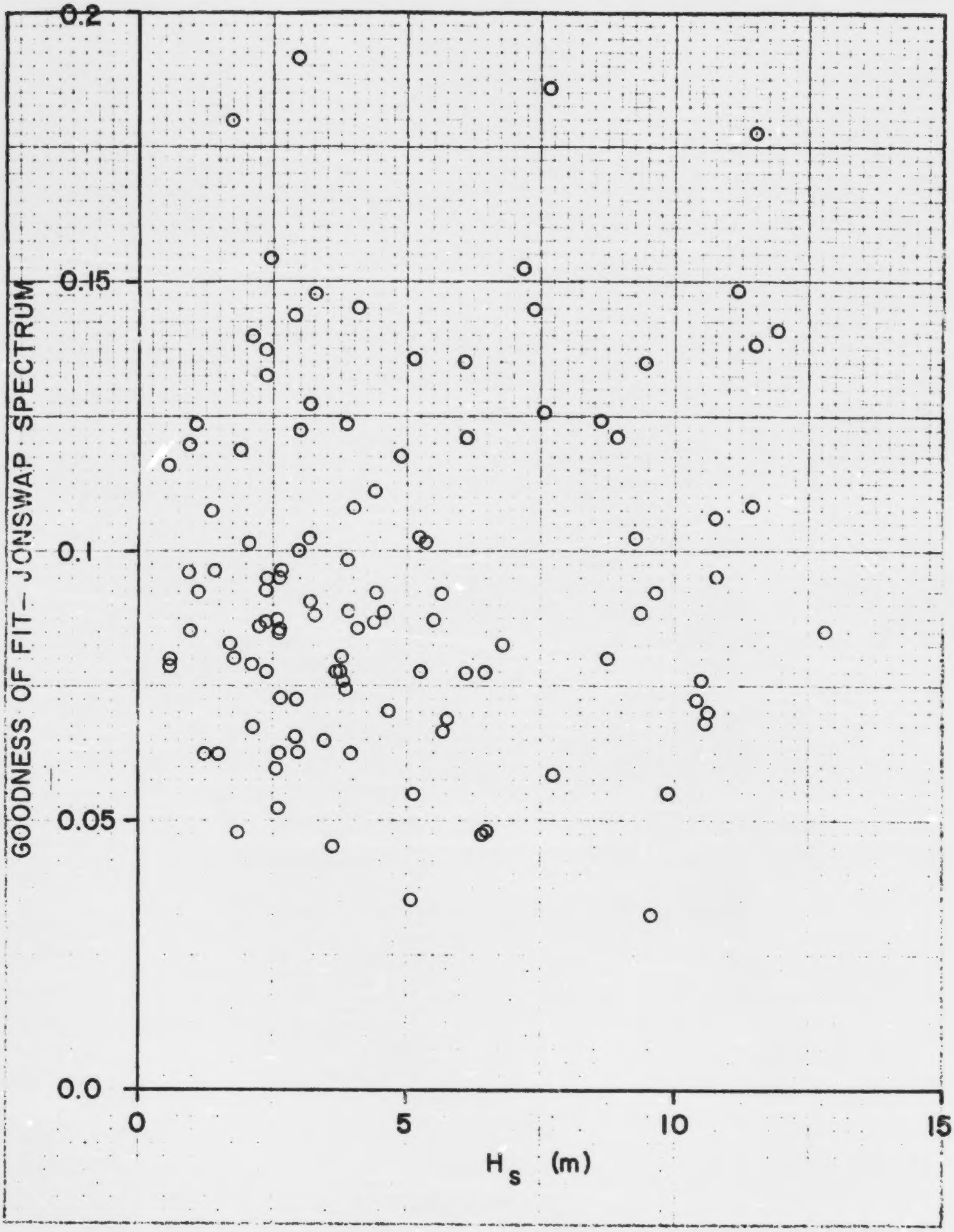

Figure 3.14 Goodness of fit of the JONSWAP spectrum to observed spectra as a function of significant wave height H_s. Small values indicate good fit.

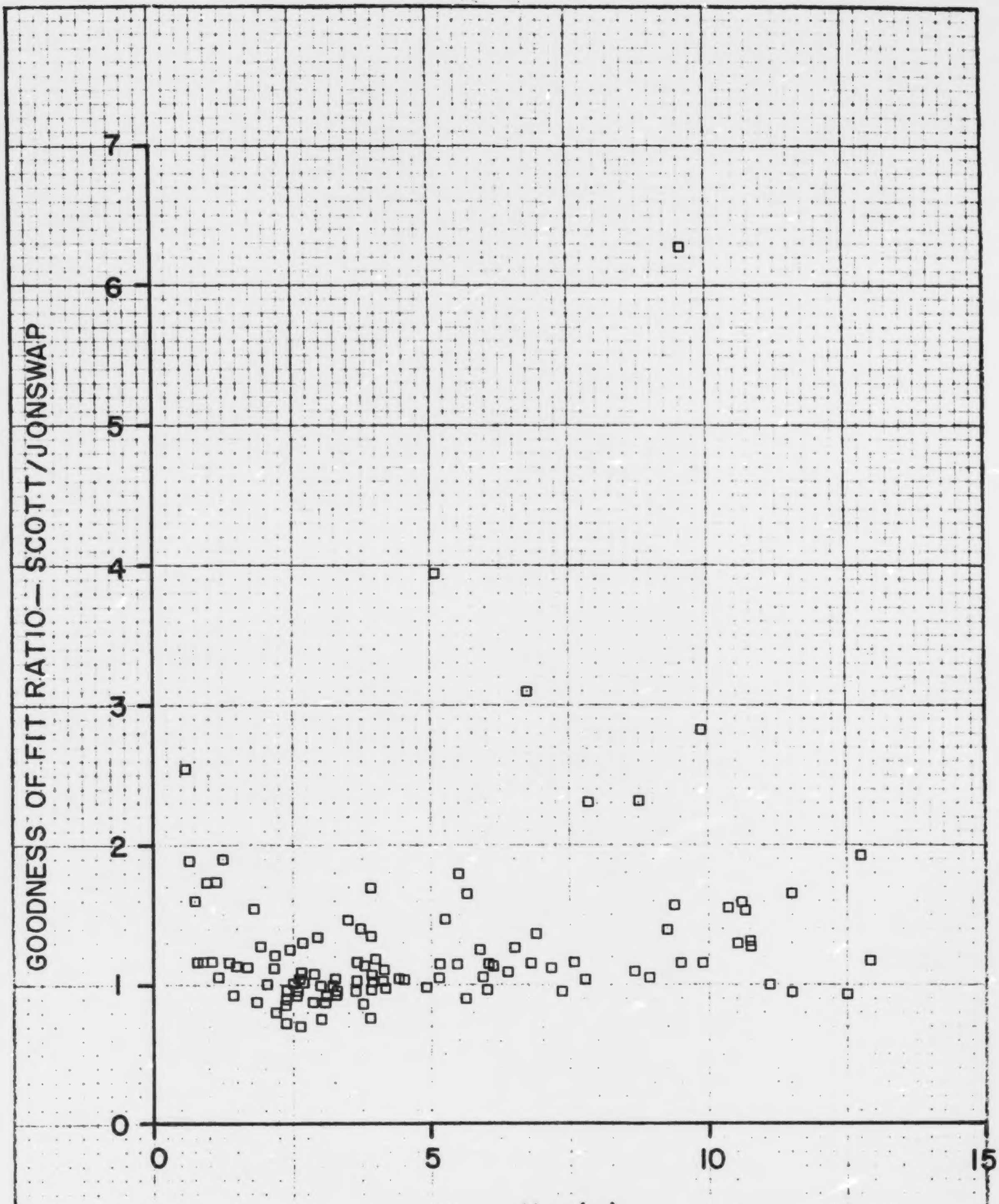

Figure 3.15 The ratio of the goodness of fit of the Scott spectrum to that of the JONSWAP spectrum as a function of significant wave height. Values above 1 mean that JONSWAP is a better fit than Scott.

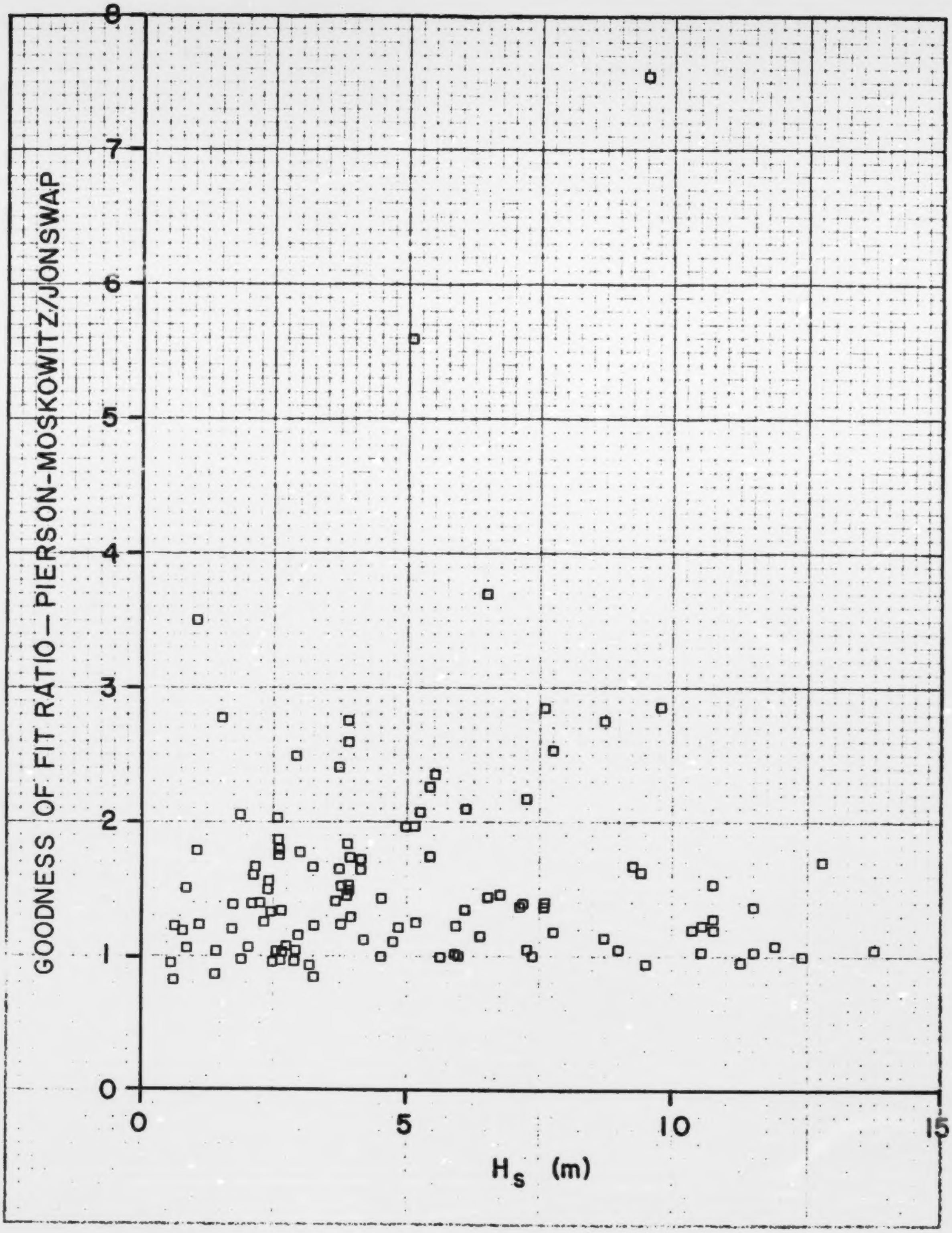

Figure 3.16 The ratio of the goodness of fit of the P.M. spectrum to that of the JONSWAP spectrum as a function of significant wave height. Values above 1 mean that JONSWAP is a better fit than P.M.

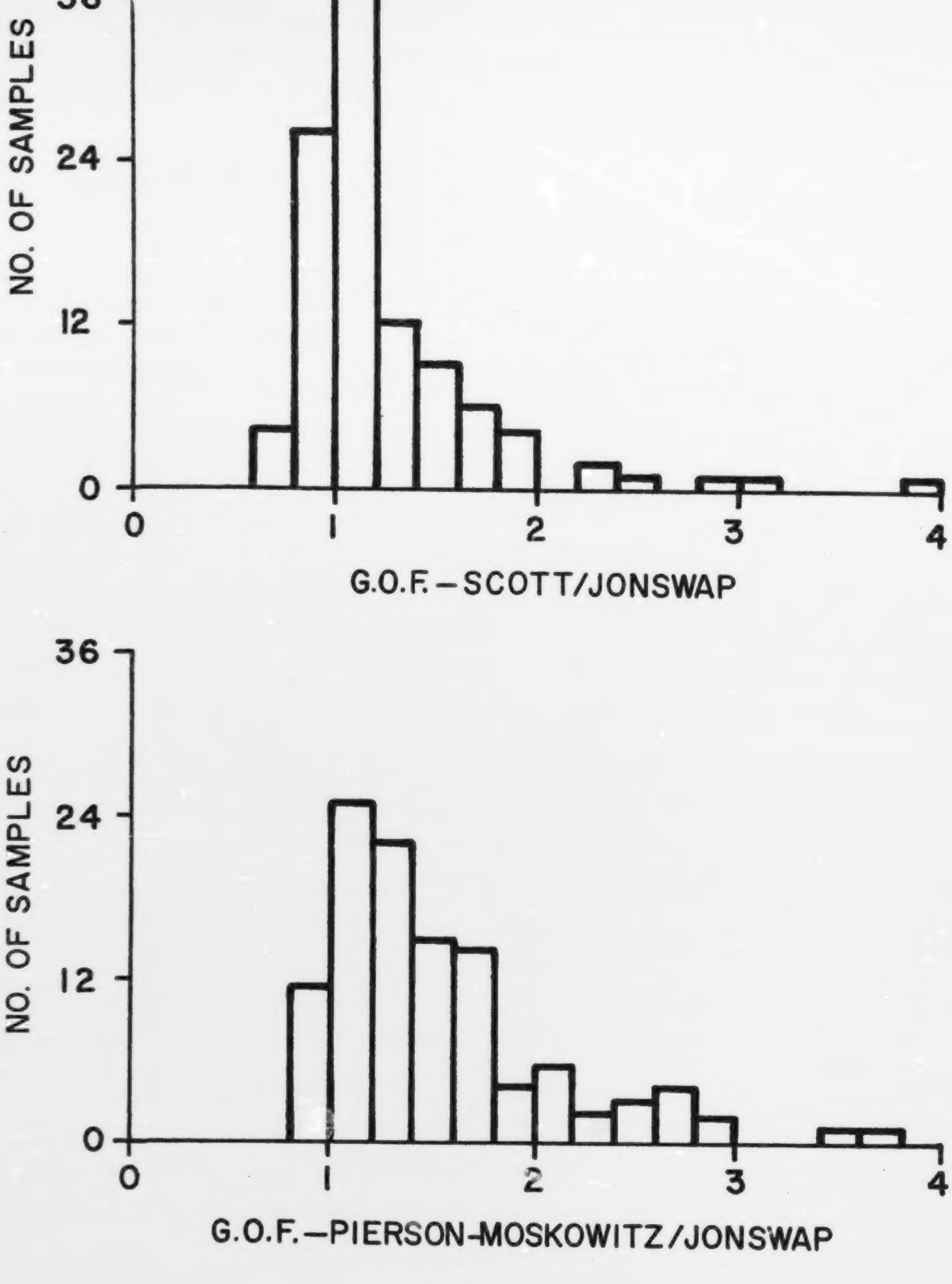

Figure 3.17 Histograms of goodness of fit ratios for the Scott and JONSWAP (above) and P.M. and JONSWAP spectra (below).

small regional differences in the results. For example, the spectra are somewhat peakier, with larger values of γ, in Lake Ontario, where fetch-limited conditions would be normally expected, than in the open sea areas. In the Beaufort Sea, the P.M./JONSWAP fit ratio seems to indicate that these two parametric spectra provide equivalent fits. A closer look at the actual curves (Spectra 101-112 in the appendix) shows that the observed spectra are very noisy and that the P.M. and JONSWAP provide equally bad rather than comparably good fits, with the latter being a better approximation to the spectral peak. It would be premature to draw any conclusions on regional differences in wave spectra on the basis of so few data, given the large amount of scatter in the results and absence of accompanying meteorological information.

A scatter plot of calculated values of γ against H_s (Figure 3.18) shows some tendency towards decreasing values of γ at larger sea-states, together with somewhat less scatter than at small values of H_s. Other observations (Chakrabarti and Snider, 1975; and Ewing, 1980) have indicated that γ decreases towards unity as fully developed conditions are approached.

Specifically, Ewing (1980) finds that $\gamma \to 1$ as the non-dimensionalized peak frequency $\upsilon = U_{10} f_M / g \to 0.13$ (with U_{10} the wind speed at 10 m, f_M the peak frequency and g the acceleration of gravity). Wind data were not used in this study to verify this observation, but there is often a tendency for γ to tend to unity at the peak of some of the observed storms, as the P.M. spectrum becomes a better fit to the observed spectrum (cf. for example the sequence of spectra 89-93). The absence of simultaneous meteorological information makes any correlation with wind speed impossible here.

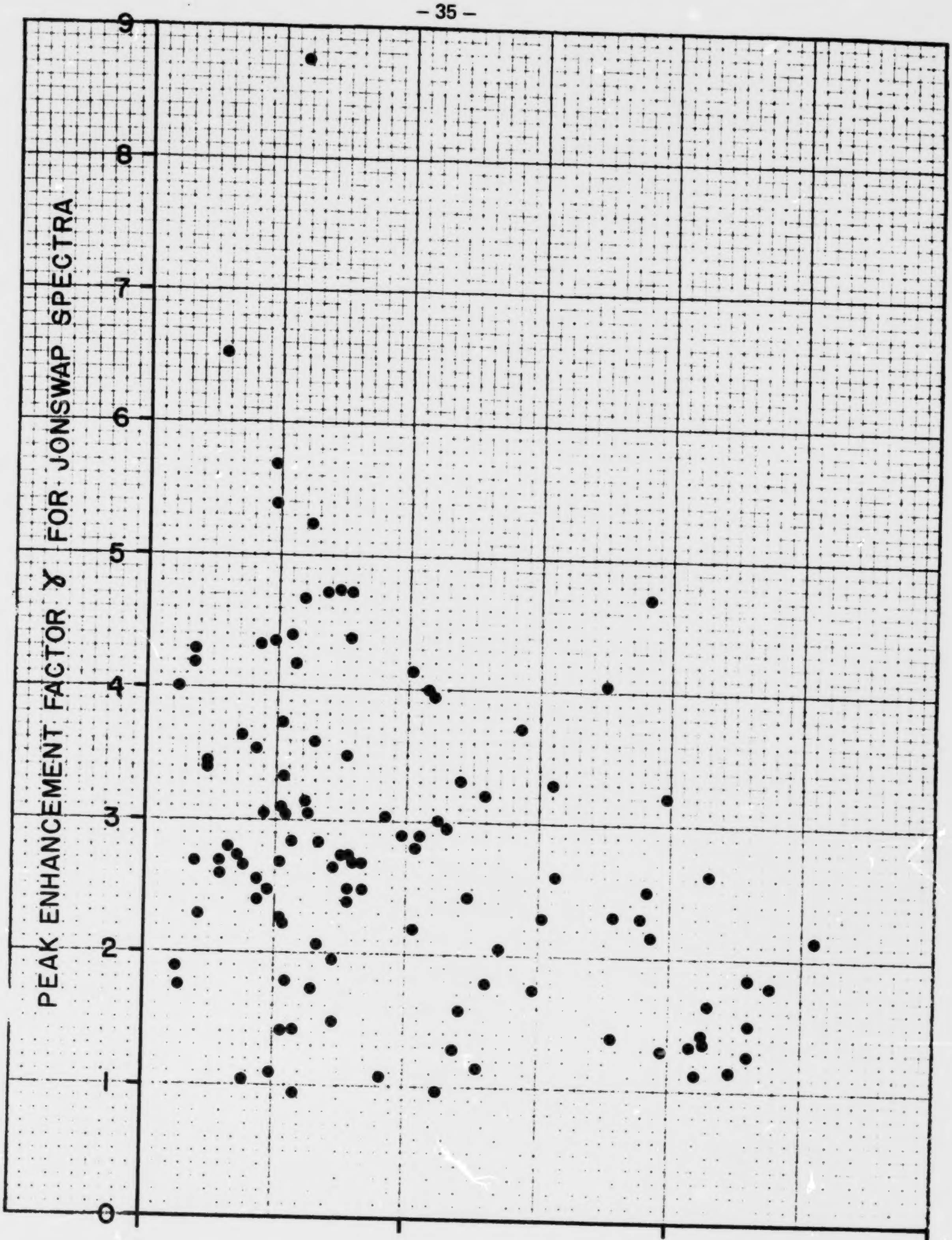

Figure 3.18 Scatter plot of the JONSWAP peak enhancement factor γ against significant wave height H_s. When γ=1, the JONSWAP spectrum reduces to the P.M. spectrum.

3.5 Reliability of Parameter Estimates

Any discussion of wave spectra must keep in mind the random nature of ocean wave processes. The power spectrum is a statistical estimate of the variance as a function of frequency. Each spectral value P(f) is known only within some error bounds. Averaging over a succession of independent estimates, or over adjacent bandwidths, increases the number of degrees of freedom and decreases the error intervals. Assuming that each value of P(f) is the average of 2N independent estimates of the values of squares of Fourier coefficients, the confidence limits for the estimate of P(f) may be found from the chi-squared distribution (e.g. see Otnes and Enochsen, 1972, pp. 216-222).

MEDS spectral estimates are normally averaged over 8 blocks in a 20-minute sample (Wilson and Baird, 1981). Assuming stationarity, each P(f) has 15 degrees of freedom (2N-1). From the chi-squared distribution, there is thus a 90% chance that the true spectral estimate P_o lies in the range $0.6 < P_o/P < 2.0$. Each observed spectrum should then be considered as surrounded by a band of uncertainty extending to the levels given by this inequality. In particular, two spectra where 90% confidence intervals overlap cannot be considered statistically different at that level of confidence. Similarly, and this is a crucial point in fitting parametric spectra to the observed values, two parametric spectral curves which both lie within the confidence intervals of the observed spectrum are not statistically different than each other, even though one may appear to follow the observed curve more faithfully than the other. The 90% confidence levels have been superimposed on Spectra 24-26 (Figures 3.4-3.6) for a few frequencies for visual comparison. An examination of the spectral fits shows that the Scott and JONSWAP spectra are usually within the confidence limits of the observed spectrum while the P.M. spectral peak is often below the lower 90% confidence level.

Spectra are sometimes characterized in terms of their moments or quantities derived therefrom, such as the width parameter ε or the peakedness parameter Q_p. The significant wave height H_s is the simplest representation of the amplitude of the waves and is given in terms of the zeroth moment by (3.2). Estimates of spectral moments depend on the number of degrees of freedom as well as on the high-frequency cut-off point of the spectrum. Chakrabarti and Cooley (1977) have shown that the estimates of spectral parameters become stable above about twelve degrees of freedom, a condition satisfied by all spectra examined here. Rye (1977a,b) has examined the stability of wave parameters with respect to the value of the upper frequency cut-off f_H for the JONSWAP and P.M. spectra. Only Q_p turns out to be nearly independent of f_H; the other parameters generally stabilize for a value of $f_H/f_p \gtrsim 5$. The significant wave height, the only parameter used in the parametric spectrum fit that is sensitive in this regard, stabilizes for $f_H/f_p \gtrsim 3$. In fitting the JONSWAP spectrum the approximate form (3.8) is imposed, which assumes that $f_H/f_p \to \infty$. There are thus a few cases, easily detected in the spectral graphs shown in the appendix by the large amount of energy which they contain at high frequencies (for example, spectra #8,9,101,108), in which there is some amount of high frequency variance included in the fitted spectrum which is not present in the observed spectrum. The error which this produces in the significant wave height is below 10% in these few cases.

Finally, the frequency of the peak of the spectrum, f_o, is determined only within the accuracy of the bandwidth of the spectral estimates. In a few cases, as in spectra # 8,15,18, 30,87,95, there are two very nearly equal adjacent large values of $P(f)$, so that there is some uncertainty in the choice of f_o.

3.6 Conclusions of the Spectral Fits

1. The JONSWAP spectrum has been found to provide a better fit of the observed spectra than the Pierson-Moskowitz or the Scott spectra. This better fit is achieved because of the presence of the additional parameter γ which is used to match the JONSWAP spectral peak to the observed value.

2. Both the JONSWAP and the Scott spectra generally lie within the 90% confidence intervals of the observed spectral estimates and are thus not statistically different approximations of the observed spectrum.

3. All three tested spectra are nearly equally good fits for fully developed seas, corresponding to the highest waves in a storm. The common use of the Pierson-Moskowitz spectrum for such conditions is thus justified. We note however that these conditions occur only for a small fraction of the time.

4. None of the parametric spectra examined appears to be adequate for fatigue calculations since the high frequency tail of the observed spectra show a great deal of variability which is not generally reflected in the form of the parametric spectra.

5. No one parametric spectral form adequately fits all parts of the observed spectrum for all locations and all times. Thus, although the JONSWAP spectral form may provide a better fit, given a appropriate value of γ, to almost all of the observed spectra, it is not possible to choose a single value of γ which will make a JONSWAP spectrum fit all observed spectra even within a single area significantly better than the Scott spectrum.

6. The impossibility of specifying an unambiguously best spectral form among those examined is attributed in part to the small size of the sample tested, making it

impossible to bring out clear patterns from the scatter of observed values, and also in part to the lack of meteorological data to help order and understand the spectral variations. It is clear that a determined search for an observationally well-founded parametric spectrum in any one area would require a larger set of observed spectra as a data base as well as accompanying meteorological information.

7. It has been noted that reliable and stable spectral estimates require a careful choice of frequency bandwidth, length of record and sampling frequency as well as a high enough value of the high-frequency cut-off of the spectrum.

4. PRESENTATION OF SPECTRAL WAVE INFORMATION

The current methods of presenting the non-directional spectral data in digital and graphical formats, together with the treatment of the characteristic wave height (Hm_0) and peak period (Tp) data, is valued by users and should be maintained. There are, however, several additional parameters describing the observed spectra which are readily calculated, and are valuable in examining the spectral climatology in a given area. These are:

$$m_0,\ m_1,\ m_2,\ m_3,\ m_4,\ T_{m0,1},\ T_{m0,2},\ T_{m2,4},\ \varepsilon_s,\ Q_p,$$

and ν

where m_n (Moments of Spectrum) $= \int_0^\infty f^n S(f)df$,

$T_{m0,1}$ (Average Period) $= \dfrac{m_0}{m_1}$,

$T_{m0,2}$ (Average Apparent Period) $= \left(\dfrac{m_0}{m_2}\right)^{\frac{1}{2}}$,

$T_{m2,4}$ (Apparent Crest Period) $= \left(\dfrac{m_2}{m_4}\right)^{\frac{1}{2}}$,

ε_s (Spectral Width) $= \sqrt{\dfrac{m_0 m_4 - m_2^2}{m_0 m_4}}$,

Q_p (Spectral Peakedness) $= 2\sum_{i=1}^{N} f_i P^2(f_i)\Delta f_i / m_0^2$,

and ν (Spectral Narrowness) $= \sqrt{\dfrac{m_2 m_0 - m_1^2}{m_1}}$

The statistics of these parameters, which may reveal seasonal and geographical trends, or vary with the storm characteristics which produce large sea states, are readily presented in monthly histogram plots. These variables could also be shown in time-series formats on identical time scales and similar in form to the characteristic wave height plots presently used by MEDS.

An important aspect of presenting this type of information is documentation of the instruments from which it is derived, and the methods of calculation for individual parameters. This documentation needs to be adequate for judging the confidence limits on the various parameters and their stability. The documentation should describe:

(1) the wave measuring instrument and its response characteristics, together with an assessment of the accuracy of the energy density estimates;
(2) the calculation of the spectrum giving the Nyquist frequency, any filtering techniques applied, blocking and averaging details, and the method of calculating the Fourier Transform;
(3) the definition of the spectral moments and derived properties, and the formulas used to calculate them from the discrete spectrum.

Documentation of this type could be conveniently presented in the MEDS Users Guide.

As found in this study, the parametric spectra show great variability in how well they reproduce individual, observed spectra and in their defining parameters. The main challenge in presenting the spectral parameters (e.g. for the JONSWAP Spectrum or other spectra with parameters additional to Hm_0 and Tp) to users, will be to convey this variability in a meaningful way, related for example to long-term seasonal changes in the wave climate, or to short-term, storm-induced changes through a dependence on the fetch or duration of wind. Recommendations for presenting these data are not discussed here because it is believed to be premature to suggest that one, or even several, parametric forms are well enough established for oceanic conditions to be meaningful for specifying a wave climatology. This is discussed more fully in Chapter 5.

Directional spectra, derived either from instruments at sea (with a resolution of 0.01 Hz between 0.1 and 1 Hz and with 30° angular bandwidths) or from hindcast models, consist of up to about 1000 energy density values. The presentation of this much data is better done in graphical rather than tabular form. Outputs of individual spectra in graphical form may be made in polar forms as $P(f,\theta)$ (Figure 4.1) or as a function of the vector wave number $(P(\underset{\sim}{k})$ (Figure 4.2) with $|k|$ related to ω through the dispersion relation and the θ, the direction of propagation, via $\tan^{-1}\theta = k_x/k_y$. Stick diagrams (Figure 4.3), showing the direction of wave propagation at different frequencies are also a useful way of representing directional wave information. Wave roses of the form shown in Figure 4.4 have also been found useful in presenting the simplest directional information available.

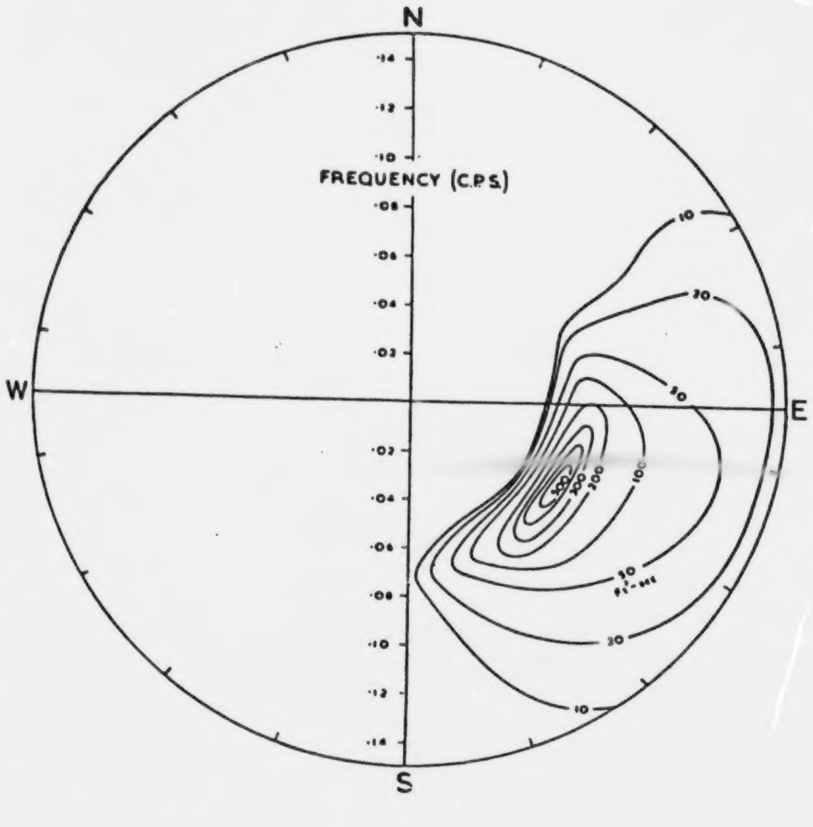

Figure 4.1 Directional spectrum S(f,θ). From Cartwright (1963).

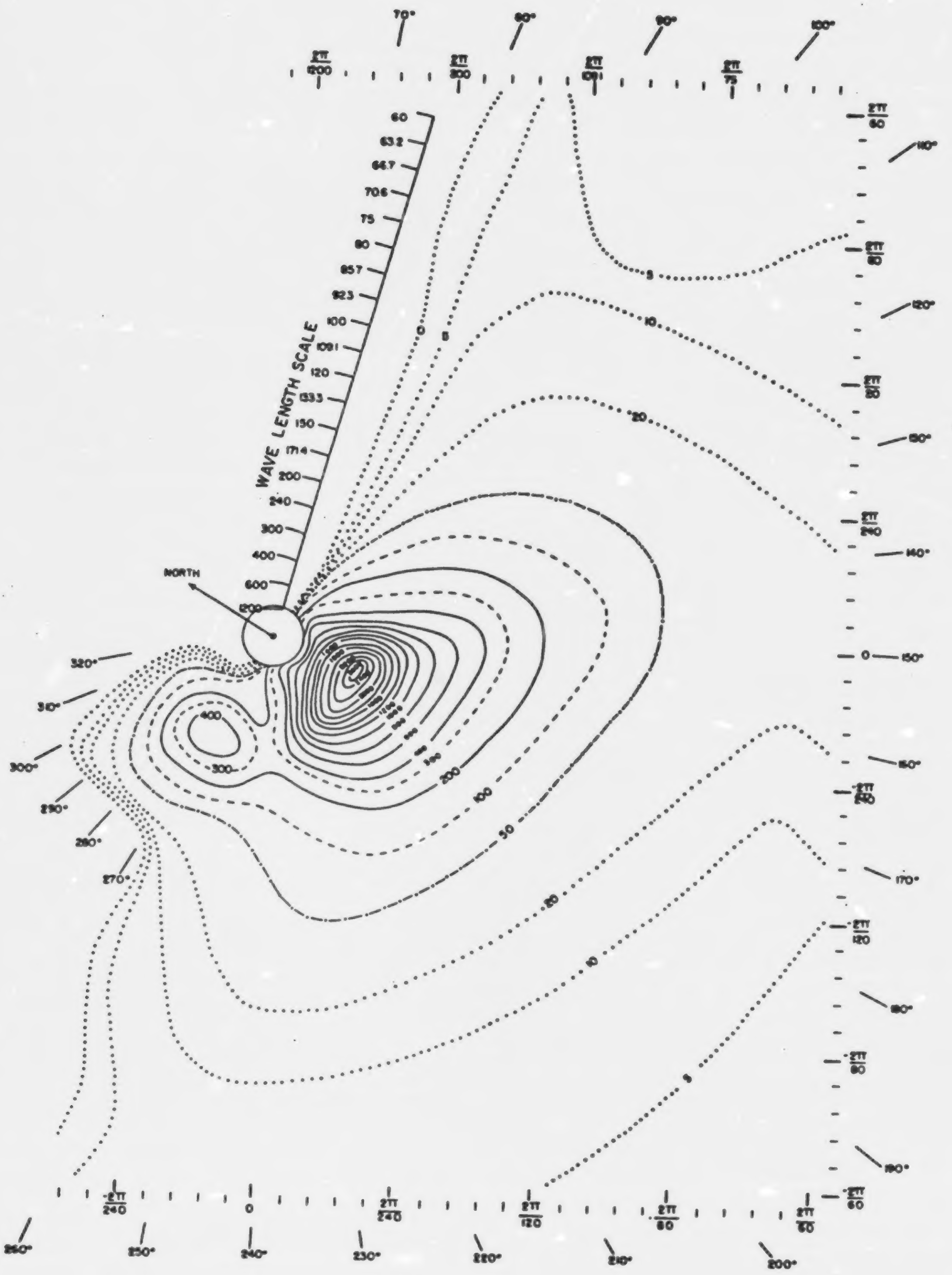

Figure 4.2 Directional spectrum S(k,θ). From Cote et al., (1960).

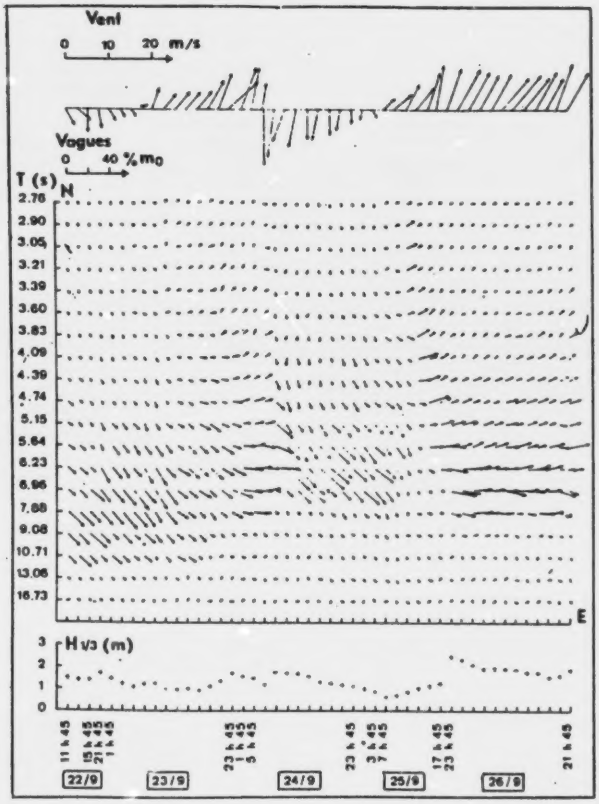

Figure 4.3 Stick diagram showing wave direction and energy content at selected frequencies. From Ezraty and Cavanié (1981).

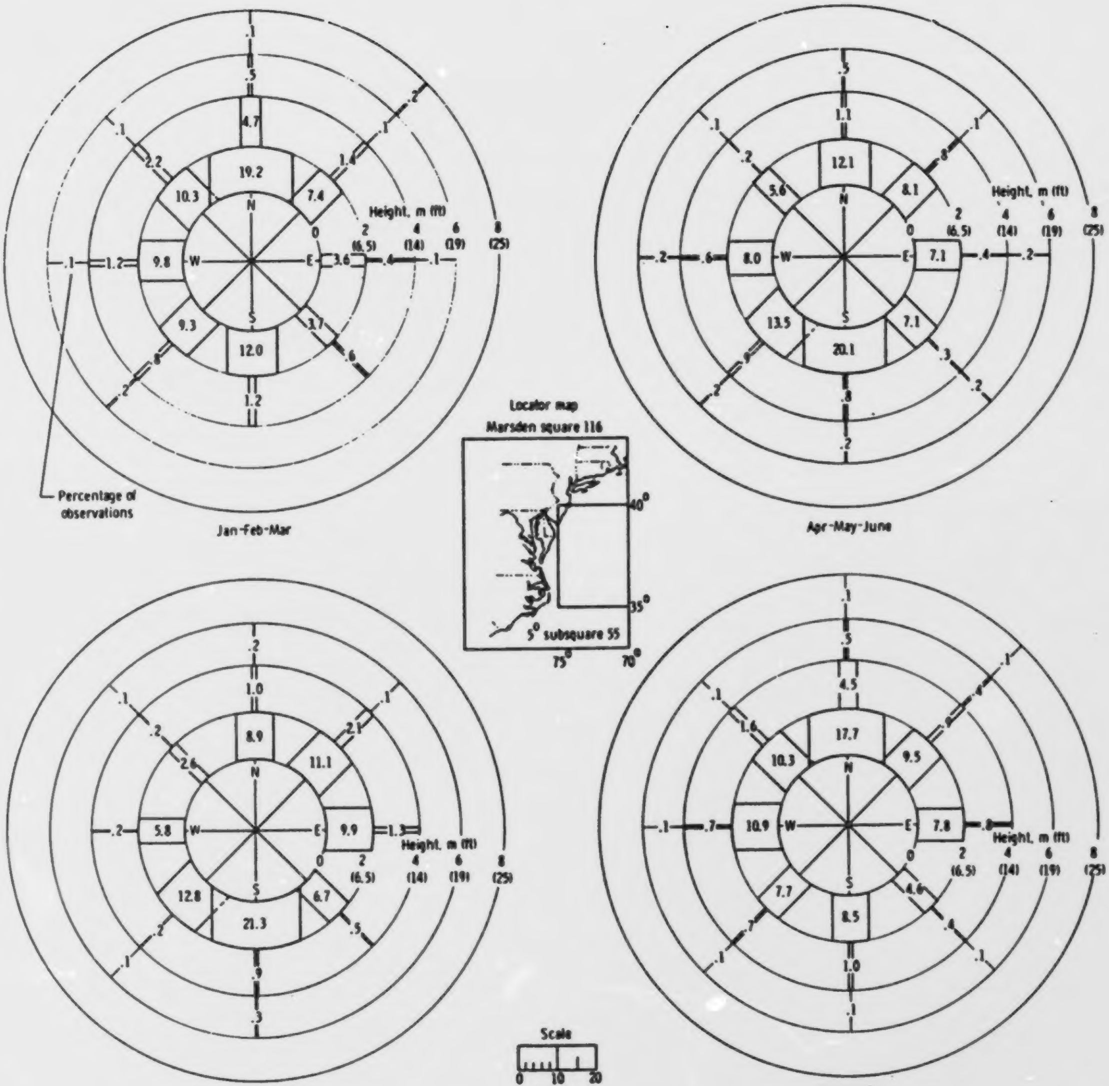

Figure 4.4 Wave roses for wave and swell information. From NASA (1974).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Although discrete spectra derived from wave measurements are used in some applications, the greatest demand for spectral wave information is in terms of parametric spectra. It is relevant to a spectral wave climatology to establish how well the various parametric forms presented in the literature model the observations, and whether one particular form is superior to the others in representing the ocean wave spectra in different areas. From the results of the present study it is concluded that the parametric spectra do reflect the principal characteristics of the measured spectra, although there is considerable variability in how well any one parametric form fits all spectra at a given location, and how well different portions of the measured spectra are fitted at different times. Thus it is appropriate to employ parametric spectra as one means of providing climatological wave data in Canadian offshore waters. Such parametric spectra can be assumed to model the energy distribution of a suitably averaged ensemble of observed spectra, i.e. averaged in such a manner as to preserve the correct relationship to the generation and decay processes.

The use of parametric spectra is justified because of the ease of dealing with only a few free parameters, instead of a complete discrete digital spectrum, and because the free parameters can be related to the physics of wave generation through a dependence on wind speed, fetch and duration (see e.g. Mitsuyasu, 1981). From the curve fitting of parametric spectra to 112 measured spectra in this study, the JONSWAP spectrum provided a fit which in most cases left an error less than 10 percent, in terms of the squares of the differences, between the two curves. In general, the three-parameter JONSWAP form fitted the data better than the Scott and Pierson-Moskowitz spectral forms, which were also examined here. In many cases, however, the JONSWAP and Scott spectra were embedded within the 90 percent confidence intervals for the spectral estimates, and thus did not constitute statistically different fits to individual spectra. The Pierson-Moskowitz (P.M.) spectrum provided a satisfactory fit only for seas which were apparently fully developed; in all other cases it grossly underestimated the energy content at the spectral peak frequency. It is also clear from the graphs in Appendix I that the P.M. spectrum consistently overestimated the energy in the high-frequency portion of the spectrum particularly just to the right of the spectral peak.

From this study it is concluded that the JONSWAP spectrum generally fits the observed spectra well, although there is no possibility of commenting on how adequate this fit is for engineering purposes without examining its use in several types of applications in detail. Furthermore, the JONSWAP form is generally superior to the Scott and P.M. formulations because of the peak enhancement factor, γ, in the JONSWAP spectrum. Mitsuyasu (1981) also found that the JONSWAP spectrum provided a good approximation to measured spectra in the generation area. Furthermore, by examining the relation of the JONSWAP parameters to the wind, Mitsuyasu established a dimensionless fetch relation for γ of the form

$$\gamma = 7.0\ \tilde{F}^{-1/7}$$

where $\tilde{F} = gF/U^2$,

F = fetch ,

g = acceleration of gravity, and

U = the wind speed.

This differs from the Hasselmann et al. (1973) conclusion that γ is approximately constant at 3.3, although showing considerable scatter about this value. In the present study the meteorological parameters, wind speed, fetch and duration, were not available with the spectra and it was not possible to determine a single value for γ applicable in all situations, or some functional dependence of this parameter on the wind field characteristics.

The two and three-parameter spectra fitted here all have severe restrictions when the oceanic spectra take on complicated forms. These situations often occur when swell and wind sea combine with well-separated peak frequencies resulting in bimodal energy distributions. In such cases the relatively simple parametric forms fail completely to capture the essential details of the observed spectra. Examples are shown in some, but not all, of the spectra for station 140 during the severe storms on the Grand Banks on January 15th and 16th, and on February 14th and 15th, 1982 (spectra 65 to 100 in the appendix). In such cases, the lower-frequency energy most often is modelled with the parametric spectrum, and the higher-frequency energy is greatly underestimated. At other times the fall-off of energy to the right of the peak frequency is very rapid, and there exists a plateau or long tail of high frequency, but low level energy which is overestimated by the fitted spectra. Ochi and Hubble (1976) recognized these trends in other north Atlantic Ocean spectra and pointed specifically to the importance of parameterizing the high-frequency energy distribution correctly for use in the design of vessels that have high-frequency response characteristics. They introduced the 6-parameter spectrum for this purpose. We believe this aspect of specifying a wave climatology requires further study. It would be potentially misleading to base a spectral climatology on a parametric spectrum which is applicable only a fraction of the time during the growth and decay cycles of the sea-state. As noted above, the interpretation of fitted parameters is done in terms of the wind characteristics that generate the waves: little of this type of interpretation is available for the 6-parameter spectrum and would logically accompany a systematic investigation of the applicability of the 6-parameter (or perhaps alternate) formulation.

5.2 Recommendations

The principal objective of this study was to provide a series of recommendations for presenting a spectral wave climatology to potential users of such information. To arrive at a generalized description of wave spectra in a given area, and in this way avoid the dissemination of a large amount of digital spectral data on a routine basis, the approach of presenting the climatology in terms of one-dimensional parametric spectra was examined. However, from the preliminary fitting of three frequently used parametric spectra to observed data in this study, it is clear that no one spectral form provides a universal model of the measured spectra at all times. Thus it is not possible to select one, or even several, parametric spectra on which to base a climatological description at this stage of the investigation. So that while specific methods of computing and presenting climatological data using parametric spectra cannot be recommended, several definite steps that can lead to a resolution of the questions surrounding the parametric spectral representation can be proposed.

An extension of this study's approach to fitting parametric to measured spectra is warranted. As many spectra as possible, at selected locations for which meteorological data are available, should be thoroughly analyzed to determine:

(1) the optimum parametric spectrum. In this respect, spectra other than those tested here should be examined, in particular the 6-parameter spectrum of Ochi and Hubble (1976) which would test the representation of high-frequency energy.

(2) the dependence of the optimum spectrum, or the type of parametric spectrum, providing the best fit or fits, and the variation of parameters on season, stage of storm or other environmental conditions.

This work should be done at a level higher than straight curve fitting by invoking the physics of wave generation through the availability of suitable meteorological information. The wind speed and direction should be available at or near the location of the wave samples during each of the storms selected. Execution of this recommendation should concentrate on areas with extensive data archives. In this regard, the Grand Banks and the Beaufort Sea are two regions having good seasonal coverage of both wave and meteorological data.

It is strongly recommended that the observed spectral properties listed in Chapter 4 be calculated for all spectra, and archived together with the discrete digital spectrum on a routine basis. Additionally, the statistics of these parameters should be calculated and presented in the wave data product booklet for each Waverider station. This recommendation pertains to both new data entering MEDS and those data already archived, since in fitting parametric spectra to observed data, relationships can then be sought between the fitted parameters and these measured properties.

It is also recommended that MEDS prepare a detailed technical document describing data acquisition and analysis. This material should include technical specifications of the measurement instrumentation such as response characteristics and limits. As outlined in Chapter 4, the analysis discussion would include filtering techniques, methods of calculation, and formulas used to calculate the spectral moments and derived properties. This material could be included in the present MEDS Users Guide.

Directional wave spectral data are now widely recognized as important for engineering design and are being acquired in offshore areas with increasing frequency. One example of this is the Federal Government program to collect wave climate data on the Northern British Columbia coast, a project which includes directional wave measuring instruments. Directional spectral data are also available from meteorologically-based wave hindcast models (Resio, 1981) and these can be used to prepare a spectral climatology, although one which must recognize the need for sound instrumental verification. With the availability of some directional spectral data now, and anticipating increasing amounts in the future, it is recommended that MEDS implement a data analysis package capable of producing estimates of mean wave direction as a function of frequency and estimates of the directional spreading functions.

In addition, the one-dimensional spectra found by integrating the directional data, and the derived properties listed in Chapter 4, should be calculated. By doing this, and routinely processing directional data that becomes available, the information required to better verify the parametric directional spectra described by Hasselmann et al. (1980), Mitsuyasu et al. (1975), and Mitsuyasu (1980) will be at hand. While it is premature to recommend parametric forms for directional spectra to user groups, this type of data processing would help to establish the correct spectral forms and, importantly, their limitations. It is further recommended that meteorological data be collected and analysed in conjunction with directional wave spectral data.

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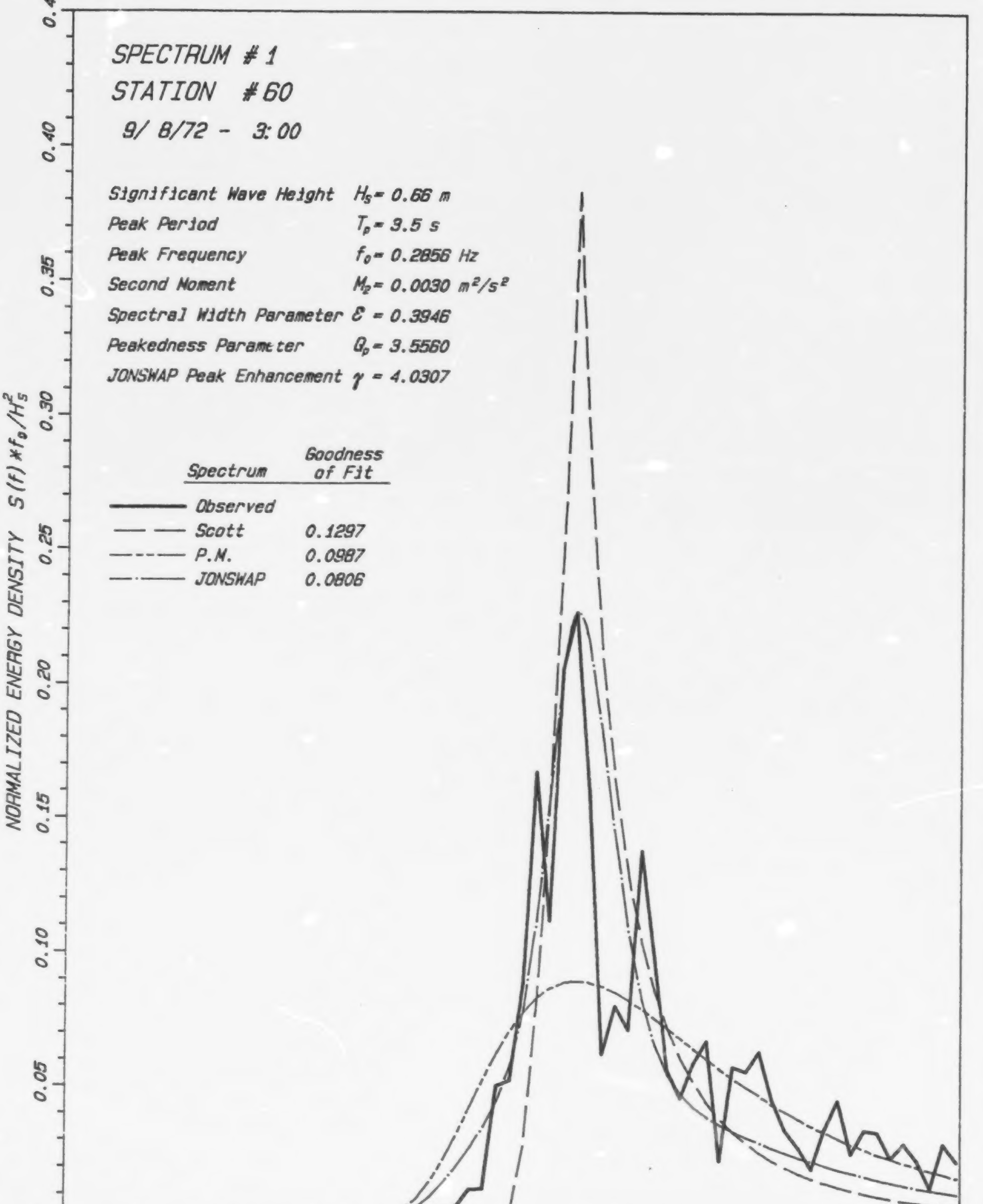
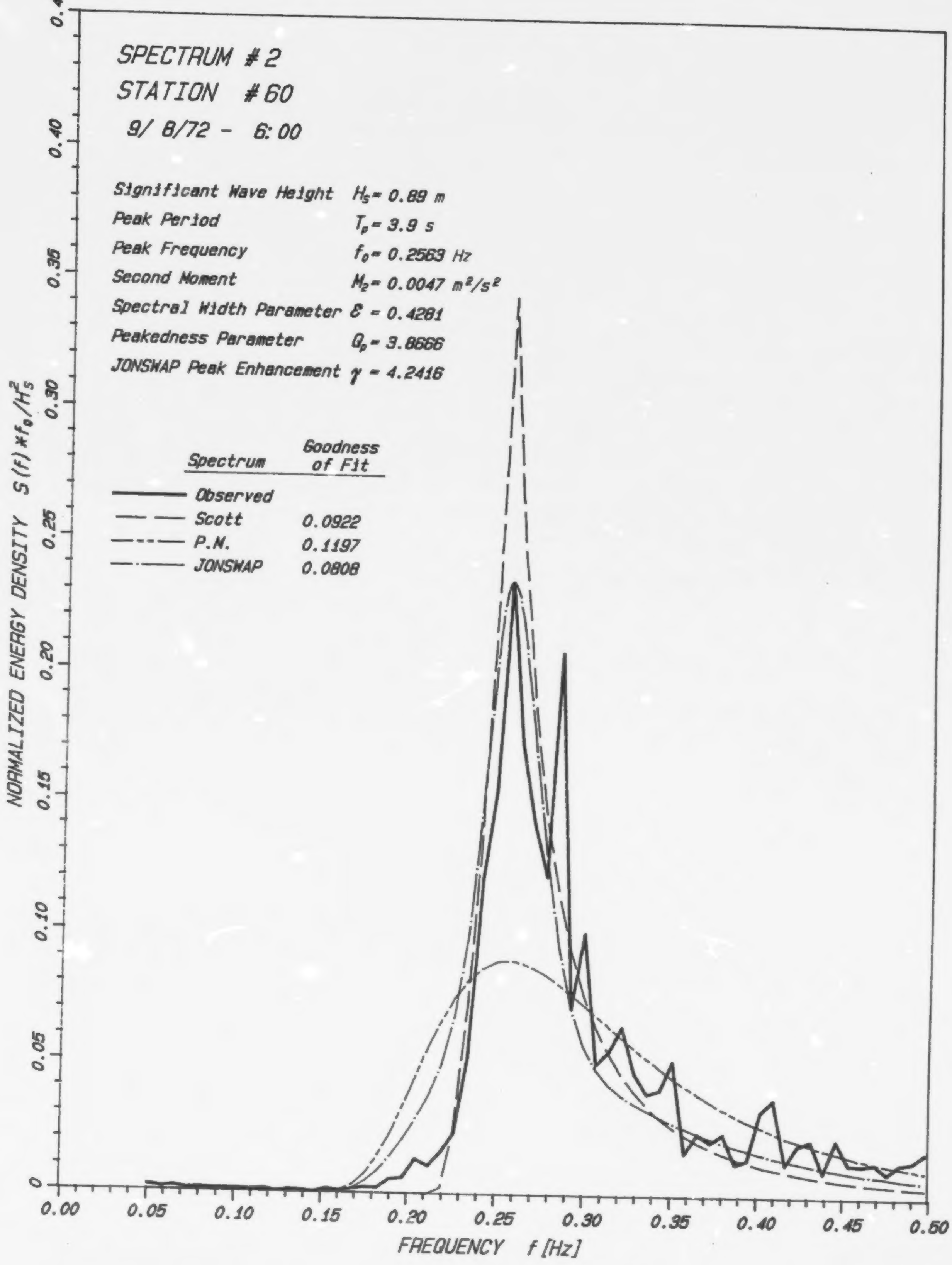
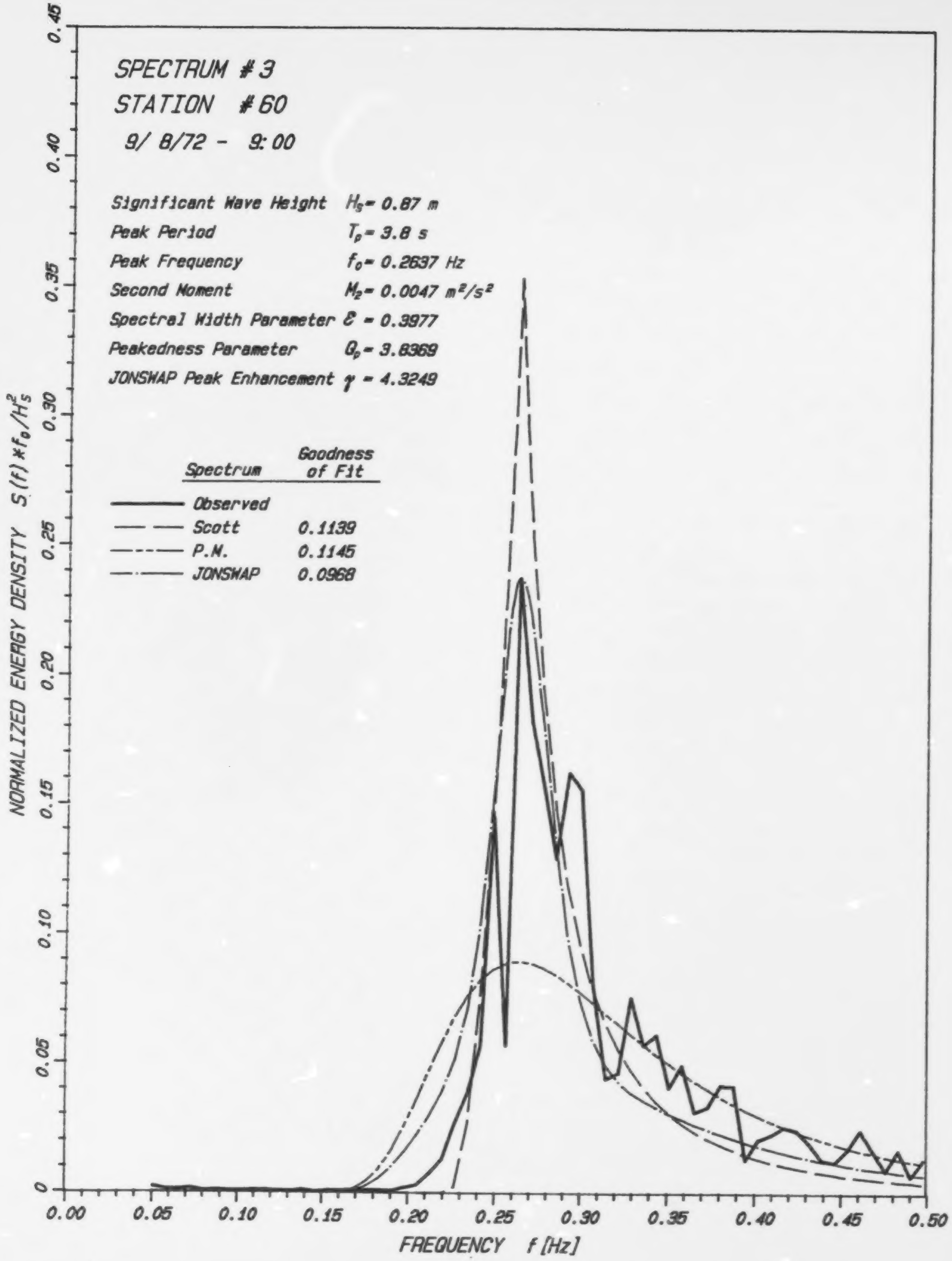
APPENDIX I

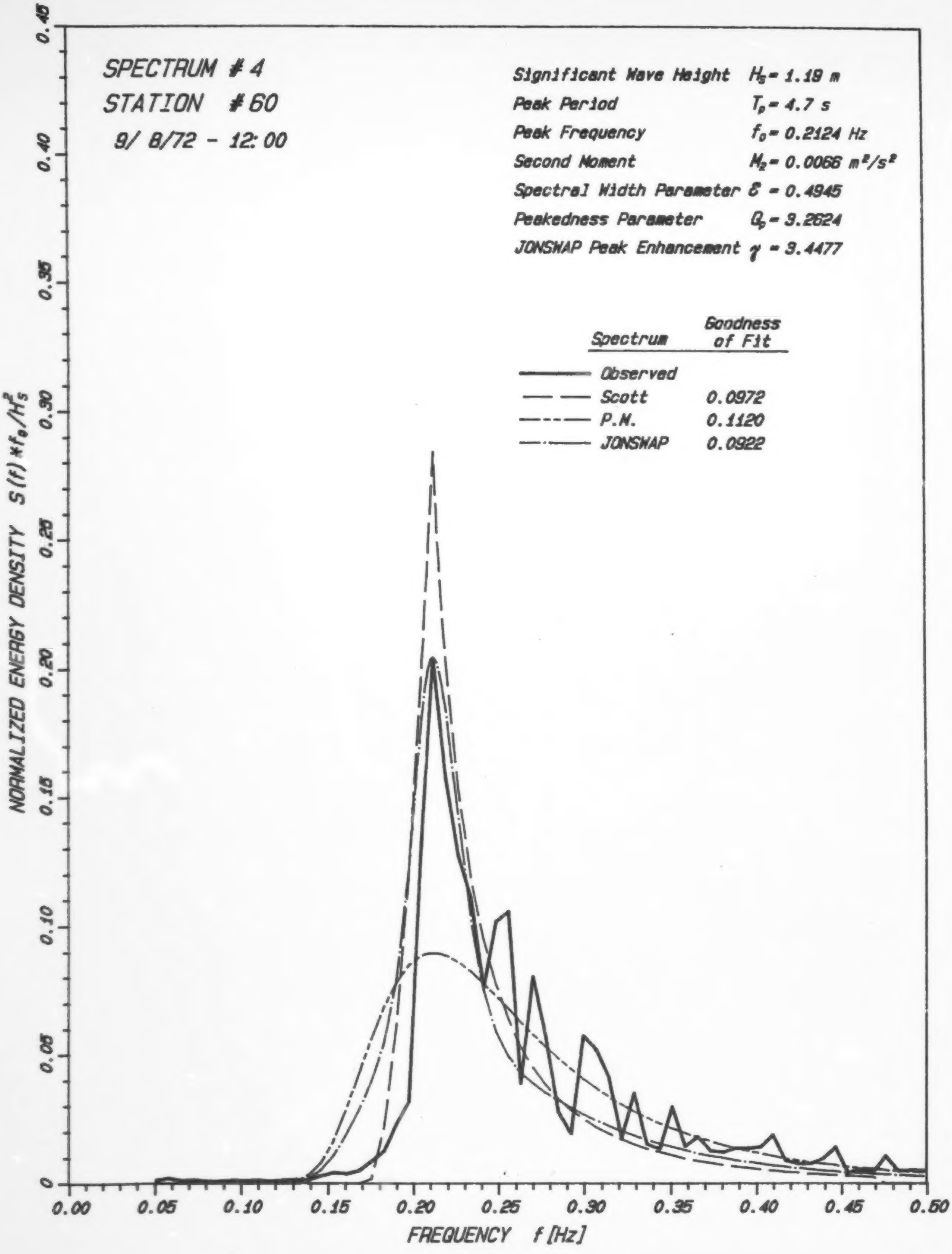
Spectra 1 - 112

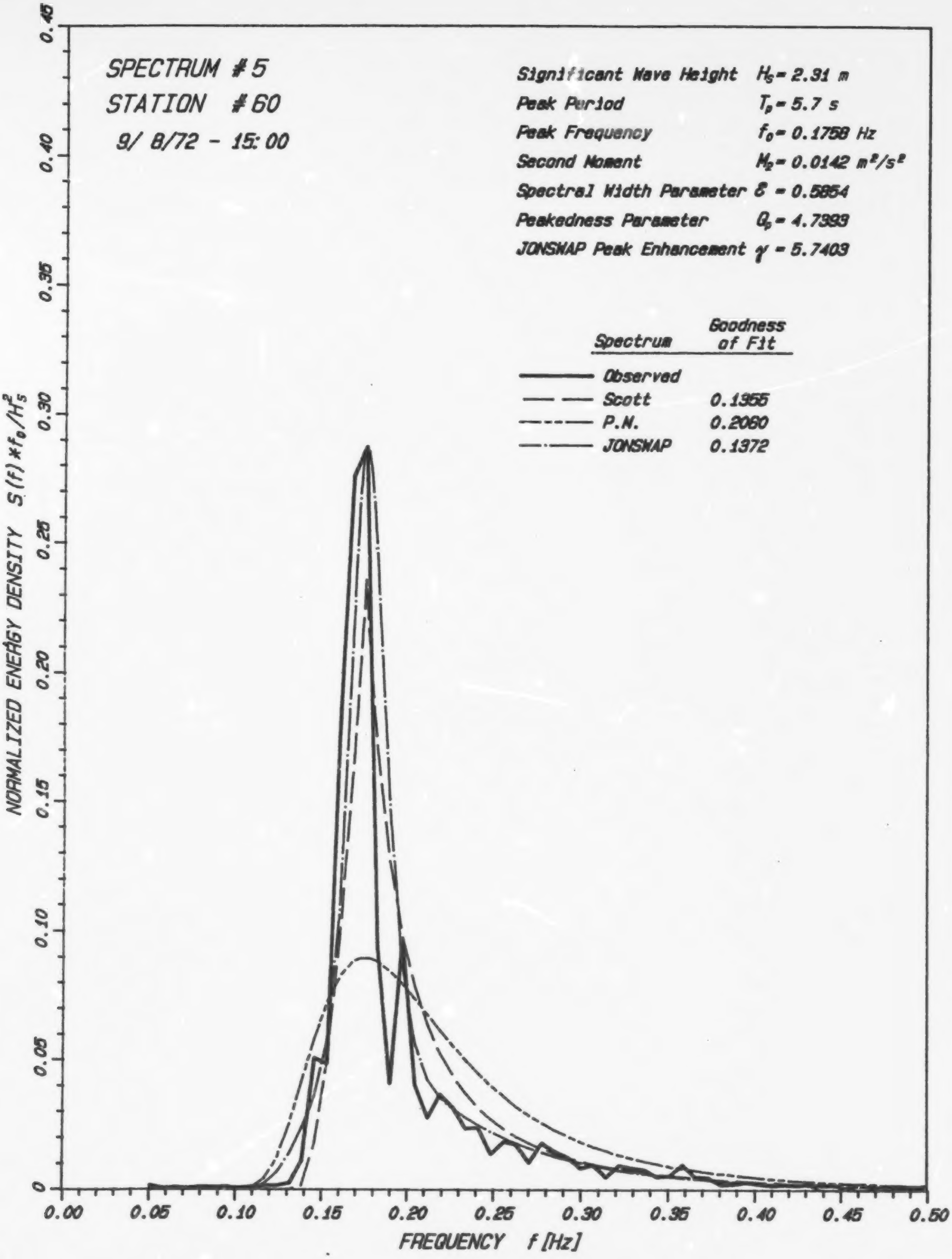
This appendix includes plots of all observed spectra provided by MEDS for analysis, together with fitted Pierson-Moskowitz, Scott and JONWSAP spectra, and estimates of various wave parameters, as defined in Chapter 3. Locations of wave measuring stations are given in Table I.


SPECTRUM # 1
STATION # 60
9/ 8/72 - 3:00
Significant Wave Height H_s = 0.66 m
Peak Period T_p = 3.5 s
Peak Frequency f_0 = 0.2856 Hz
Second Moment M_2 = 0.0030 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.3946
Peakedness Parameter Q_p = 3.5560
JONSWAP Peak Enhancement γ = 4.0307
Spectrum
Goodness of Fit
Observed
Scott 0.1297
P.M. 0.0987
JONSWAP 0.0806
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 2
STATION # 60
9/ 8/72 - 6: 00
Significant Wave Height H_s= 0.89 m
Peak Period T_p= 3.9 s
Peak Frequency f_0= 0.2563 Hz
Second Moment M_2= 0.0047 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.4281
Peakedness Parameter Q_p= 3.8666
JONSWAP Peak Enhancement γ = 4.2416
Spectrum
Goodness of Fit
Observed
Scott 0.0922
P.N. 0.1197
JONSWAP 0.0808
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 3
STATION # 60
9/ 8/72 - 9:00
Significant Wave Height H_s= 0.87 m
Peak Period T_p= 3.8 s
Peak Frequency f_0= 0.2637 Hz
Second Moment M_2= 0.0047 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.3977
Peakedness Parameter Q_p= 3.8369
JONSWAP Peak Enhancement γ = 4.3249
Spectrum
Goodness of Fit
Observed
Scott 0.1139
P.M. 0.1145
JONSWAP 0.0968
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 4
STATION # 60
9/ 8/72 - 12: 00
Significant Wave Height H_s = 1.19 m
Peak Period T_p = 4.7 s
Peak Frequency f_0 = 0.2124 Hz
Second Moment M_2 = 0.0066 m^2/s^2
Spectral Width Parameter ε = 0.4945
Peakedness Parameter Q_p = 3.2624
JONSWAP Peak Enhancement γ = 3.4477
Spectrum
Goodness of Fit
Observed
Scott 0.0972
P.M. 0.1120
JONSWAP 0.0922
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]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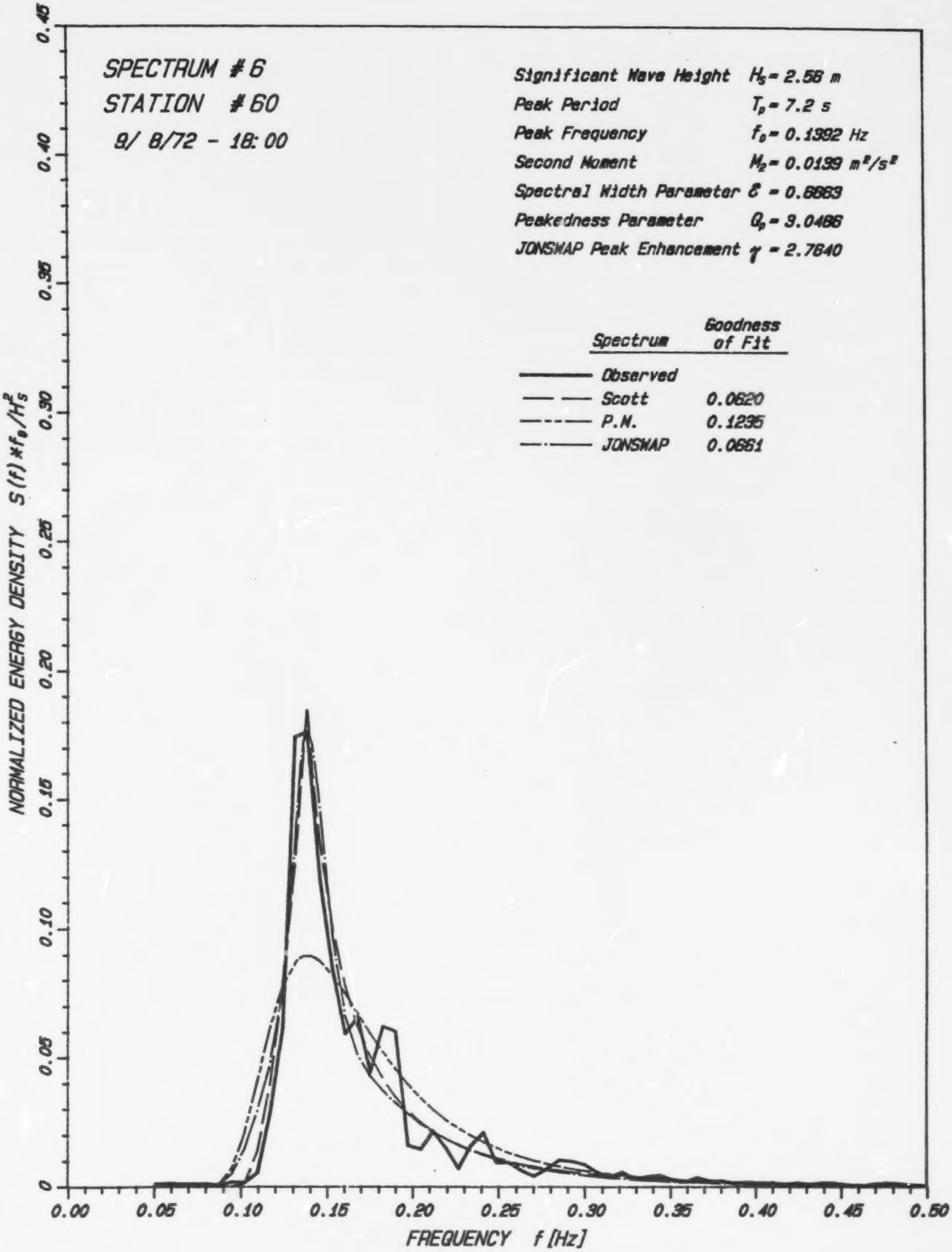
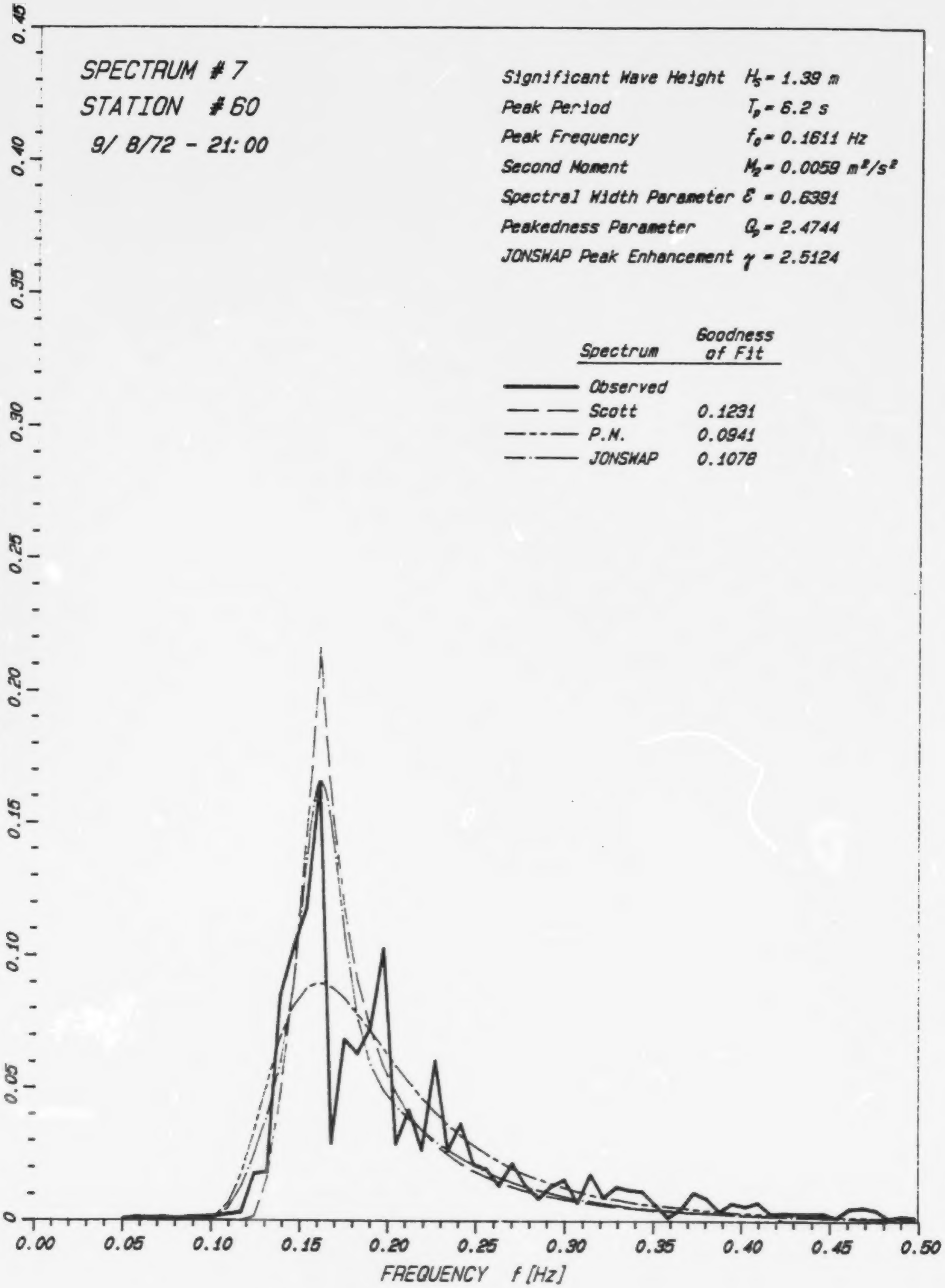
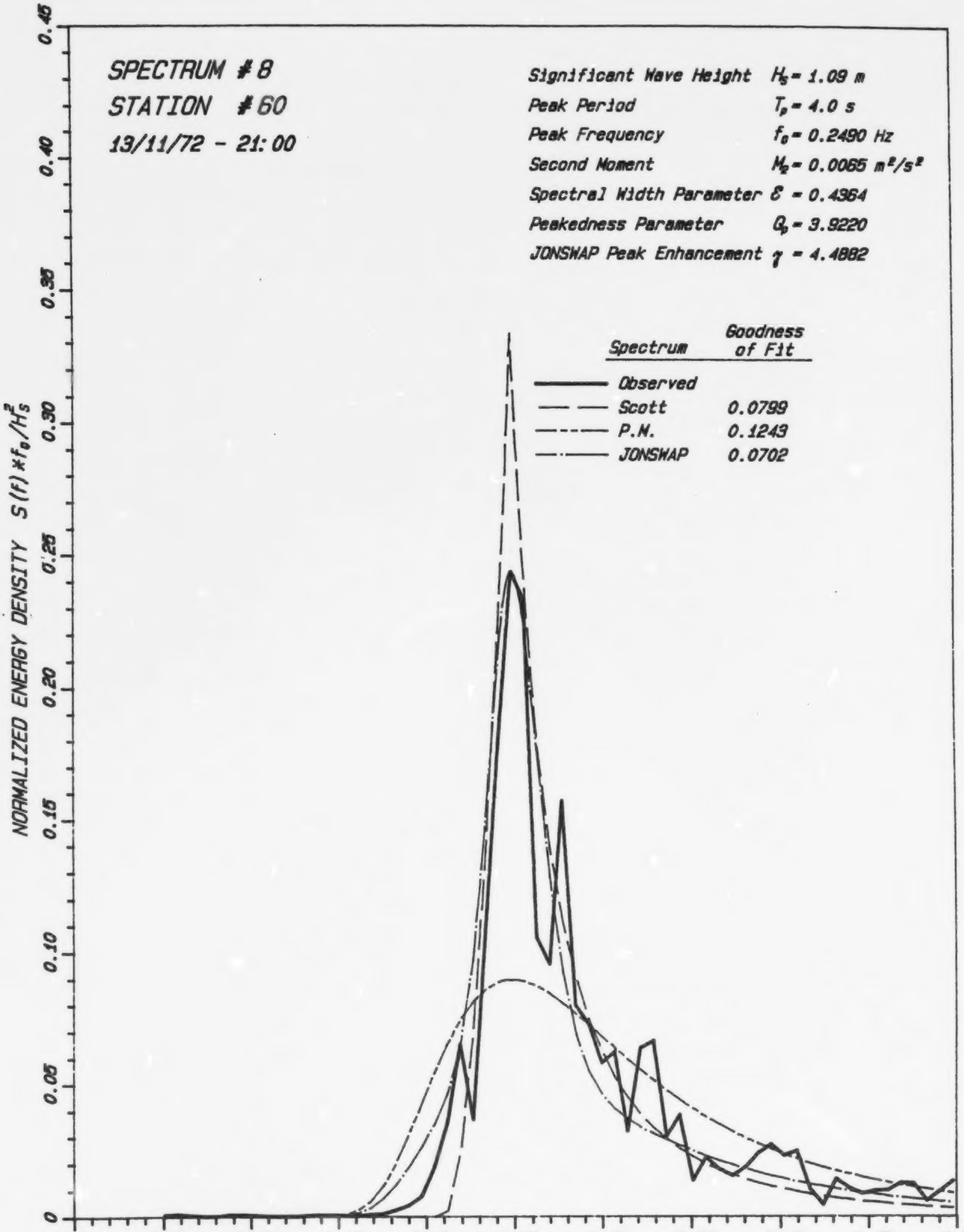
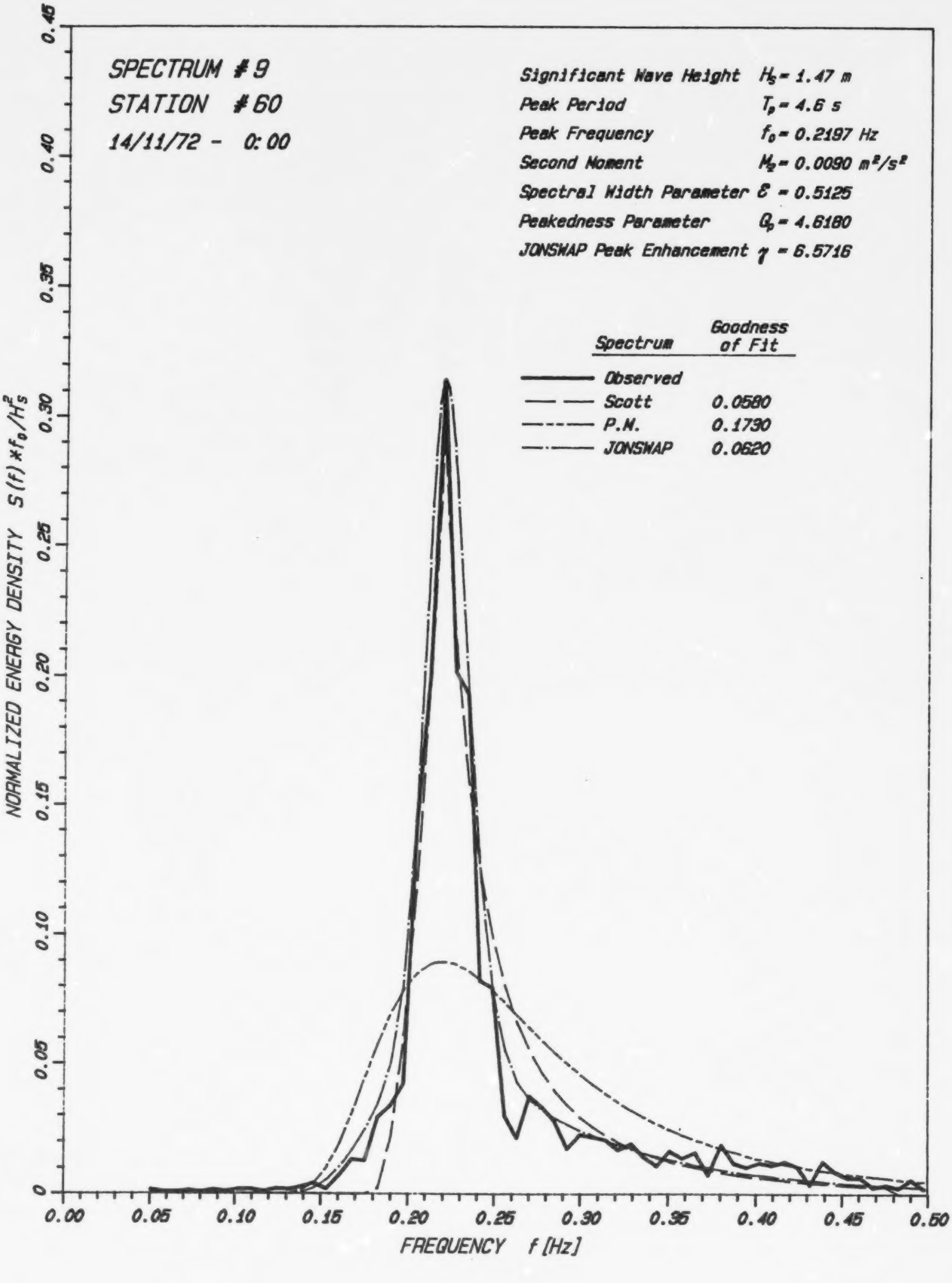
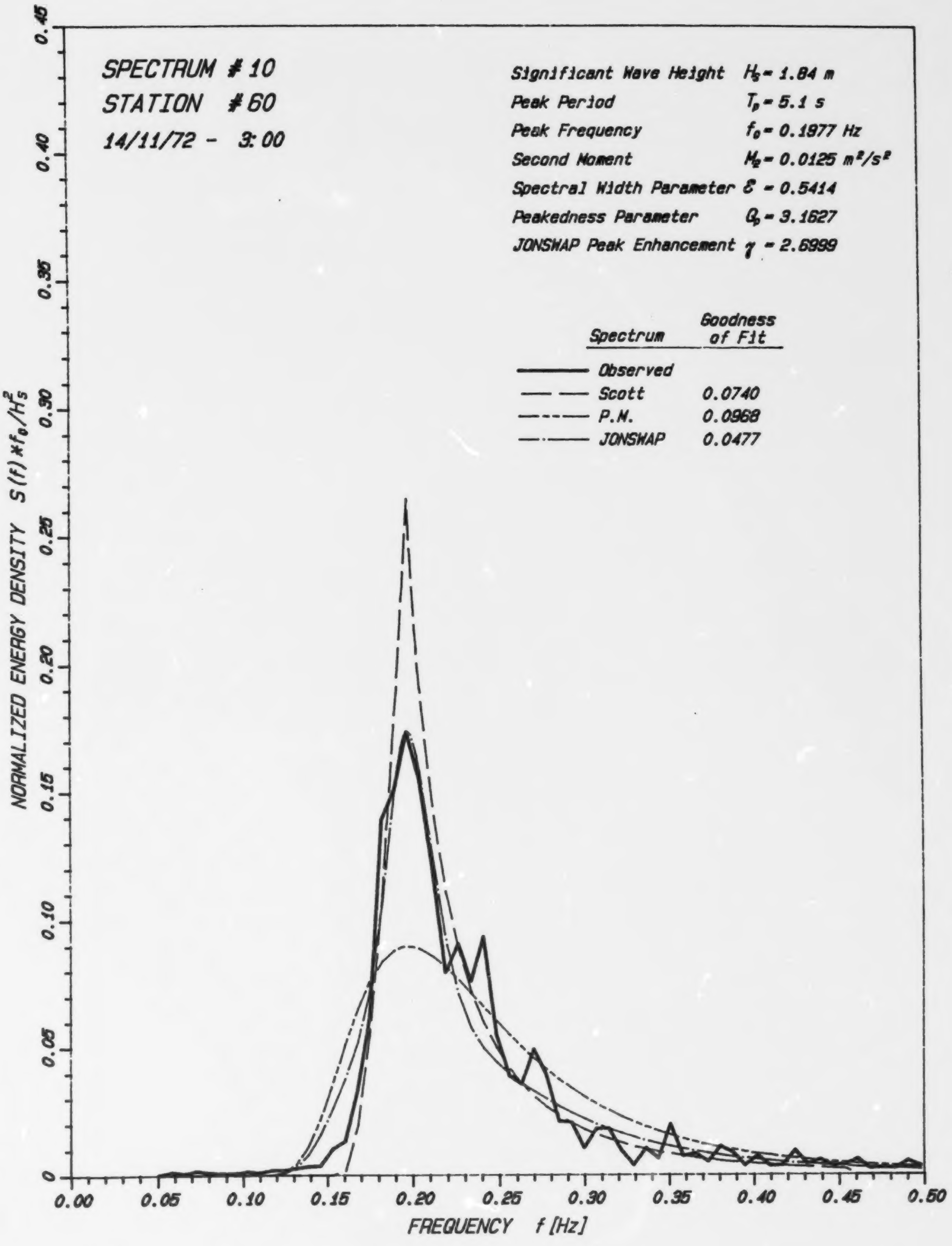
STATION # 60
9/ 8/72 - 15: 00
Significant Wave Height $H_s = 2.31$ m
Peak Period $T_p = 5.7$ s
Peak Frequency $f_0 = 0.1758$ Hz
Second Moment $M_2 = 0.0142$ m²/s²
Spectral Width Parameter $\varepsilon = 0.5854$
Peakedness Parameter $Q_p = 4.7393$
JONSWAP Peak Enhancement $\gamma = 5.7403$
Spectrum
Goodness of Fit
Observed
Scott 0.1355
P.N. 0.2060
JONSWAP 0.1372
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

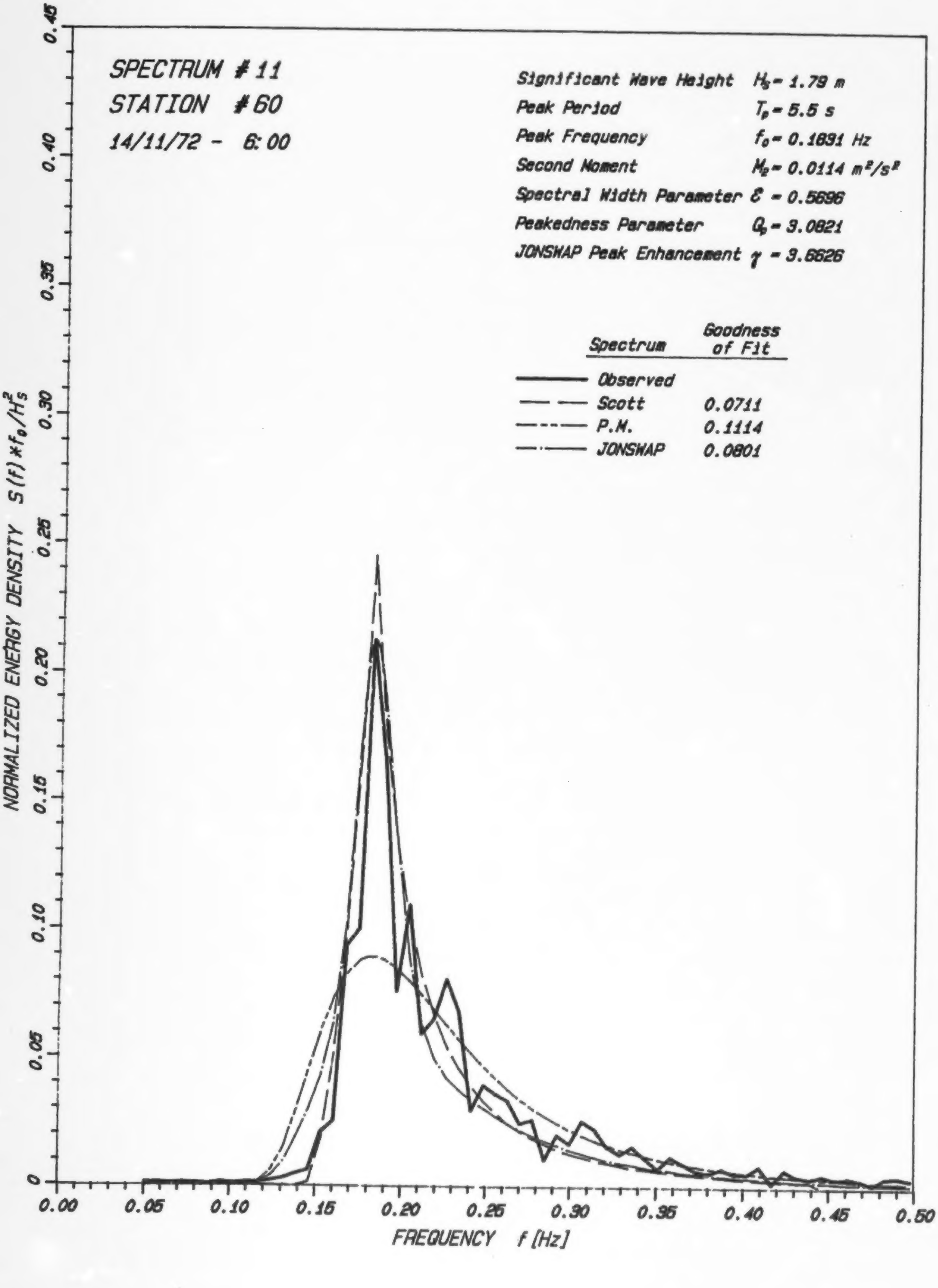

SPECTRUM # 6
STATION # 60
9/ 8/72 - 18:00
Significant Wave Height H_s = 2.56 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0139 m²/s²
Spectral Width Parameter ε = 0.6663
Peakedness Parameter Q_p = 3.0466
JONSWAP Peak Enhancement γ = 2.7640
Spectrum
Goodness of Fit
Observed
Scott 0.0620
P.M. 0.1235
JONSWAP 0.0661
NORMALIZED ENERGY DENSITY S(f)*f₀/H²ₛ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

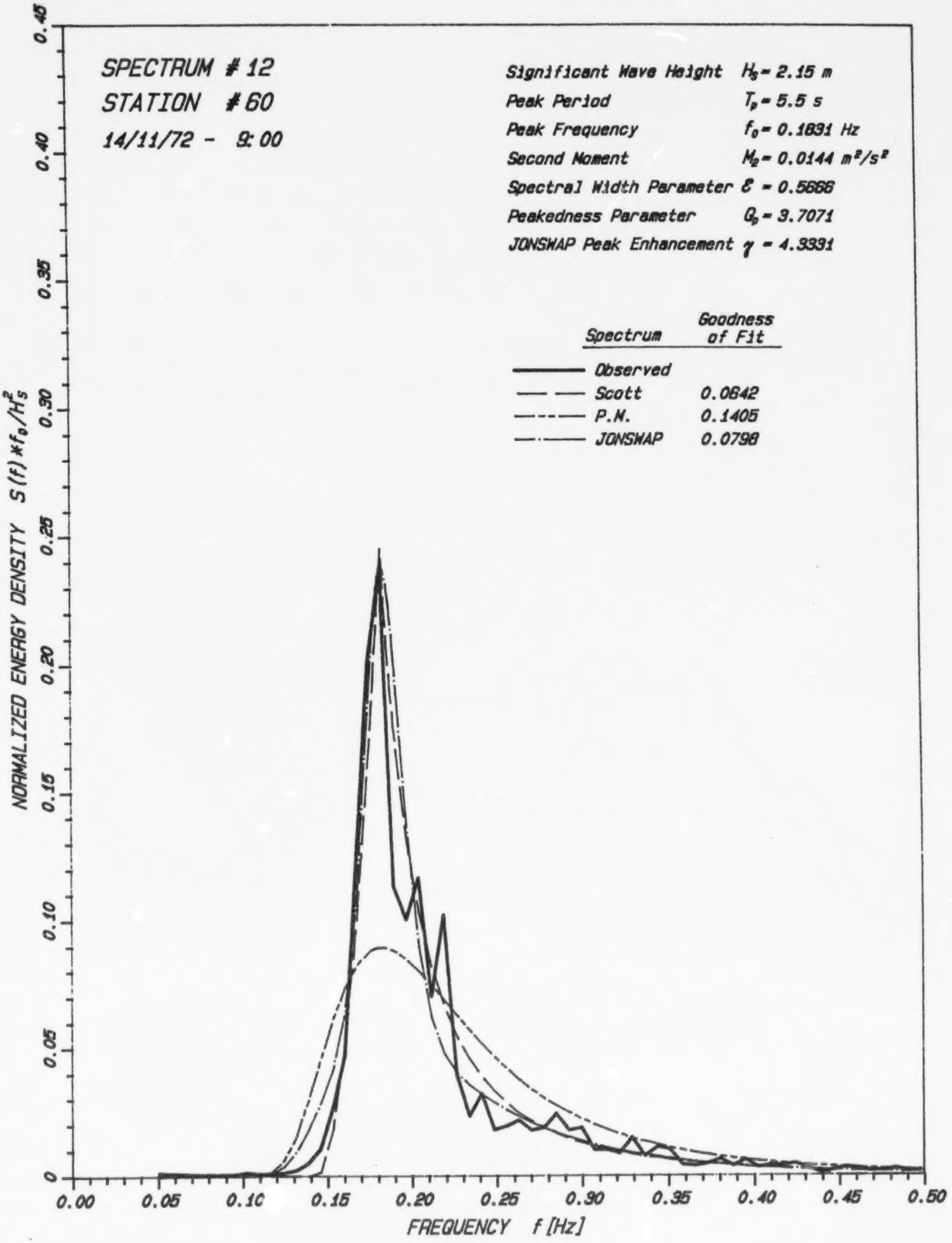

SPECTRUM # 7
STATION # 60
9/ 8/72 - 21:00
Significant Wave Height H_s = 1.39 m
Peak Period T_p = 6.2 s
Peak Frequency f_0 = 0.1611 Hz
Second Moment M_2 = 0.0059 m²/s²
Spectral Width Parameter ε = 0.6391
Peakedness Parameter Q_p = 2.4744
JONSWAP Peak Enhancement γ = 2.5124
Spectrum
Goodness of Fit
Observed
Scott 0.1231
P.M. 0.0941
JONSWAP 0.1078
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

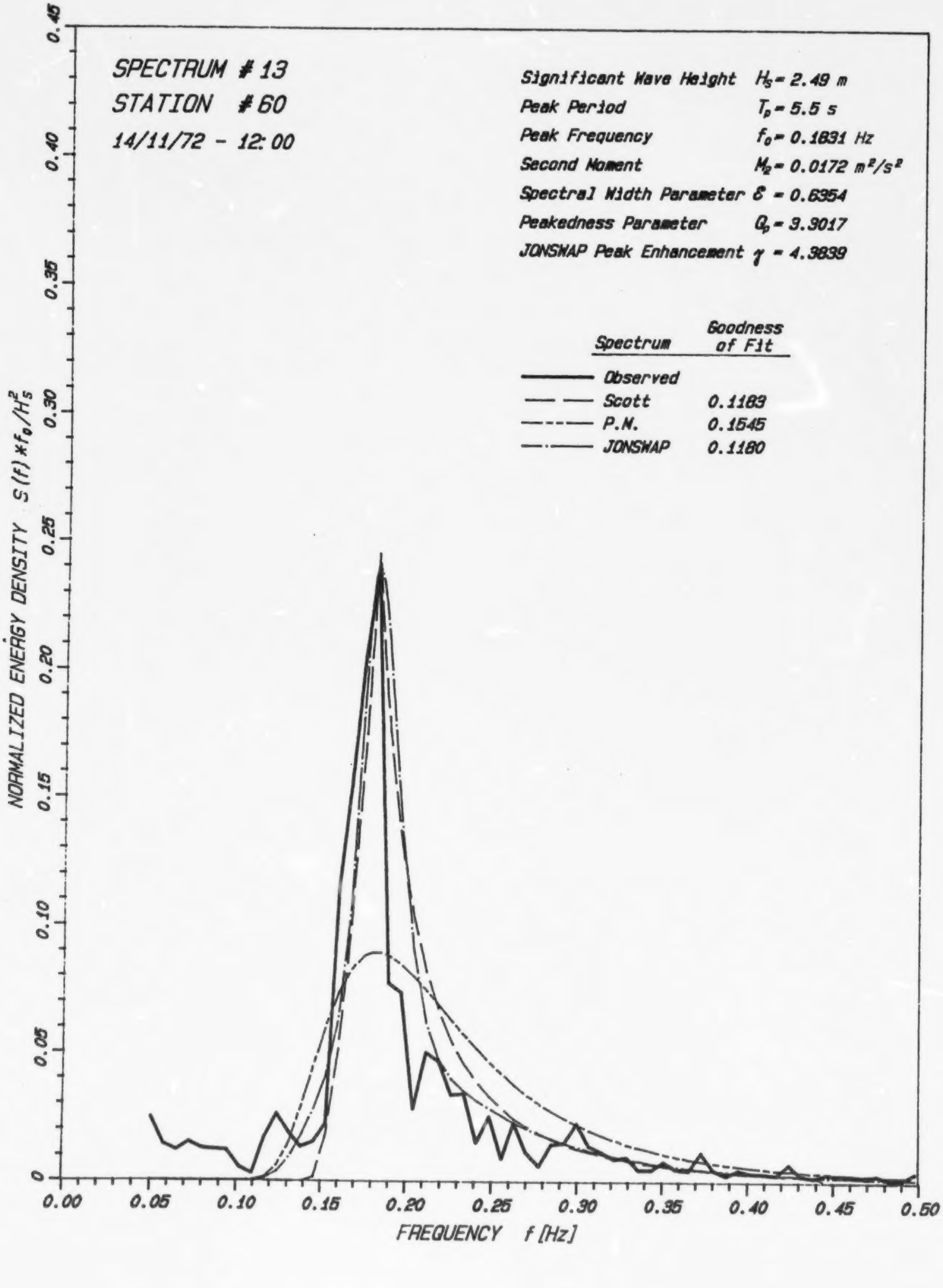

SPECTRUM # 8
STATION # 60
13/11/72 - 21: 00
Significant Wave Height H_s = 1.09 m
Peak Period T_p = 4.0 s
Peak Frequency f_0 = 0.2490 Hz
Second Moment M_2 = 0.0065 m²/s²
Spectral Width Parameter ε = 0.4364
Peakedness Parameter Q_p = 3.9220
JONSWAP Peak Enhancement γ = 4.4882
Spectrum
Goodness of Fit
Observed
Scott 0.0799
P.M. 0.1243
JONSWAP 0.0702
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

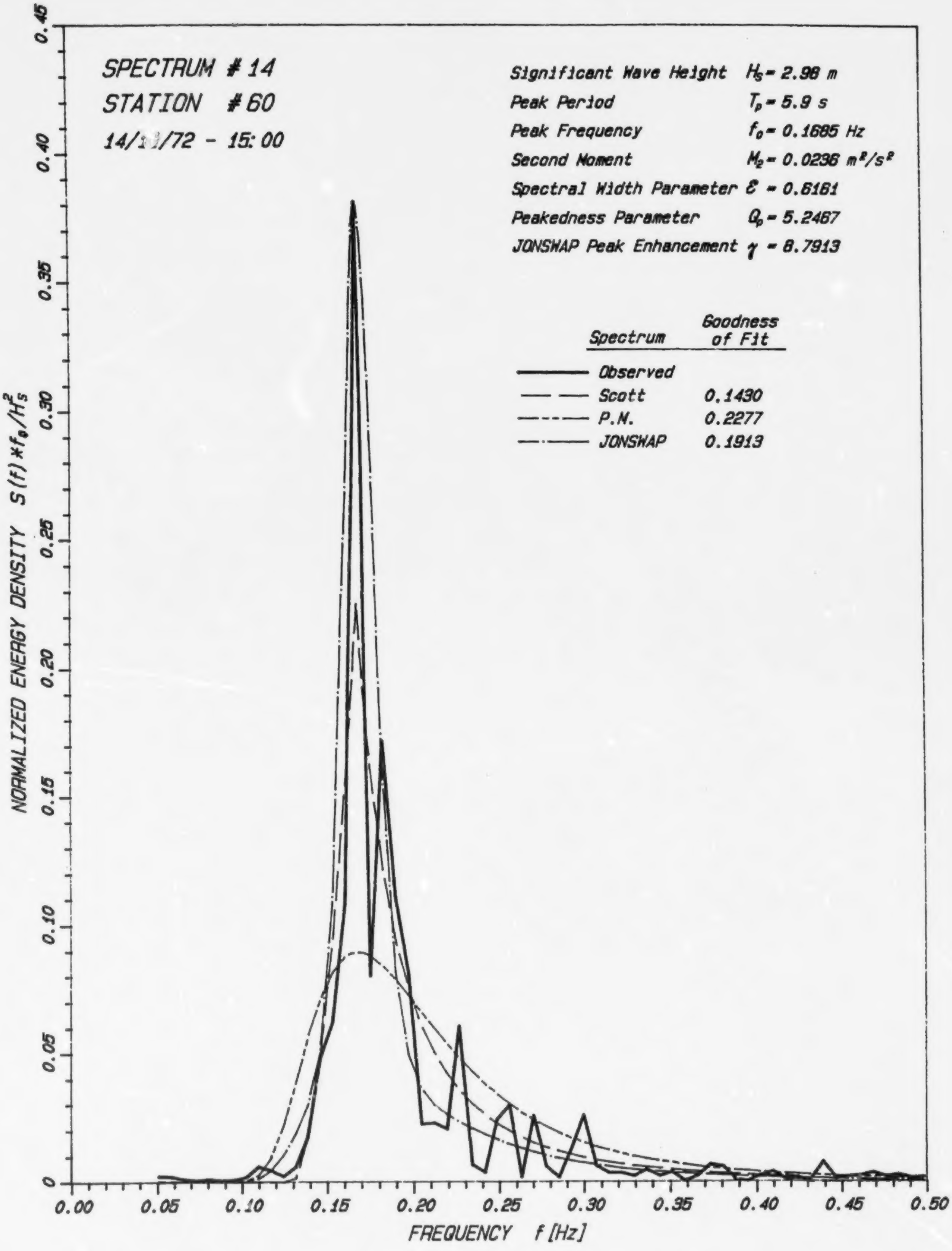

SPECTRUM # 9
STATION # 60
14/11/72 - 0:00
Significant Wave Height H_S = 1.47 m
Peak Period T_p = 4.6 s
Peak Frequency f_0 = 0.2197 Hz
Second Moment M_2 = 0.0090 m²/s²
Spectral Width Parameter ε = 0.5125
Peakedness Parameter Q_p = 4.6180
JONSWAP Peak Enhancement γ = 6.5716
Spectrum
Goodness of Fit
Observed
Scott 0.0580
P.M. 0.1730
JONSWAP 0.0620
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

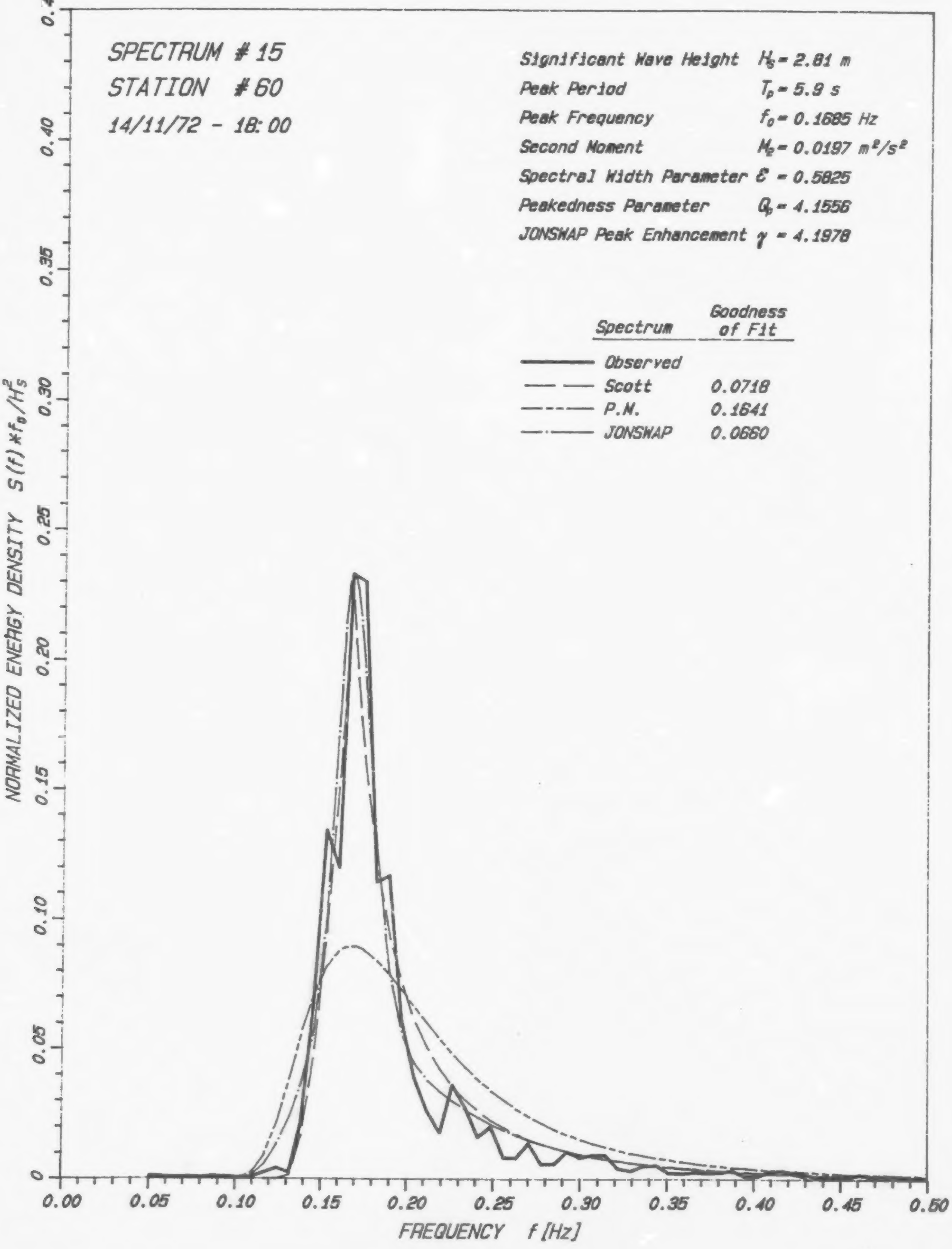

SPECTRUM # 10
STATION # 60
14/11/72 - 3:00
Significant Wave Height H_s = 1.84 m
Peak Period T_p = 5.1 s
Peak Frequency f_0 = 0.1977 Hz
Second Moment M_2 = 0.0125 m^2/s^2
Spectral Width Parameter ε = 0.5414
Peakedness Parameter Q_p = 3.1627
JONSWAP Peak Enhancement γ = 2.6999
Spectrum
Goodness of Fit
Observed
Scott 0.0740
P.M. 0.0968
JONSWAP 0.0477
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

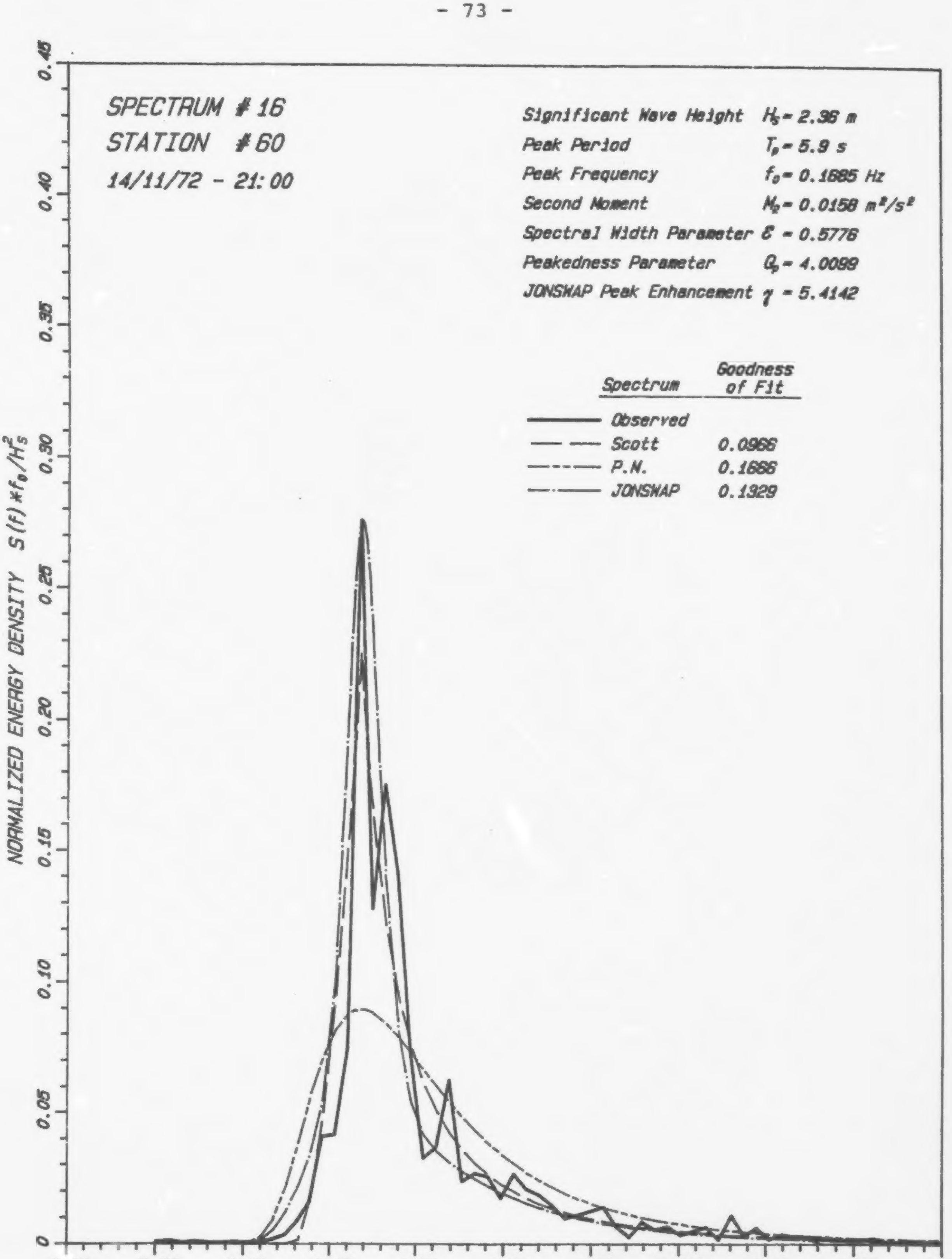

SPECTRUM # 11
STATION # 60
14/11/72 - 6:00
Significant Wave Height H_s = 1.79 m
Peak Period T_p = 5.5 s
Peak Frequency f_0 = 0.1891 Hz
Second Moment M_2 = 0.0114 m^2/s^2
Spectral Width Parameter ε = 0.5696
Peakedness Parameter Q_p = 3.0821
JONSWAP Peak Enhancement γ = 3.6626
Spectrum
Goodness of Fit
Observed
Scott 0.0711
P.M. 0.1114
JONSWAP 0.0801
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

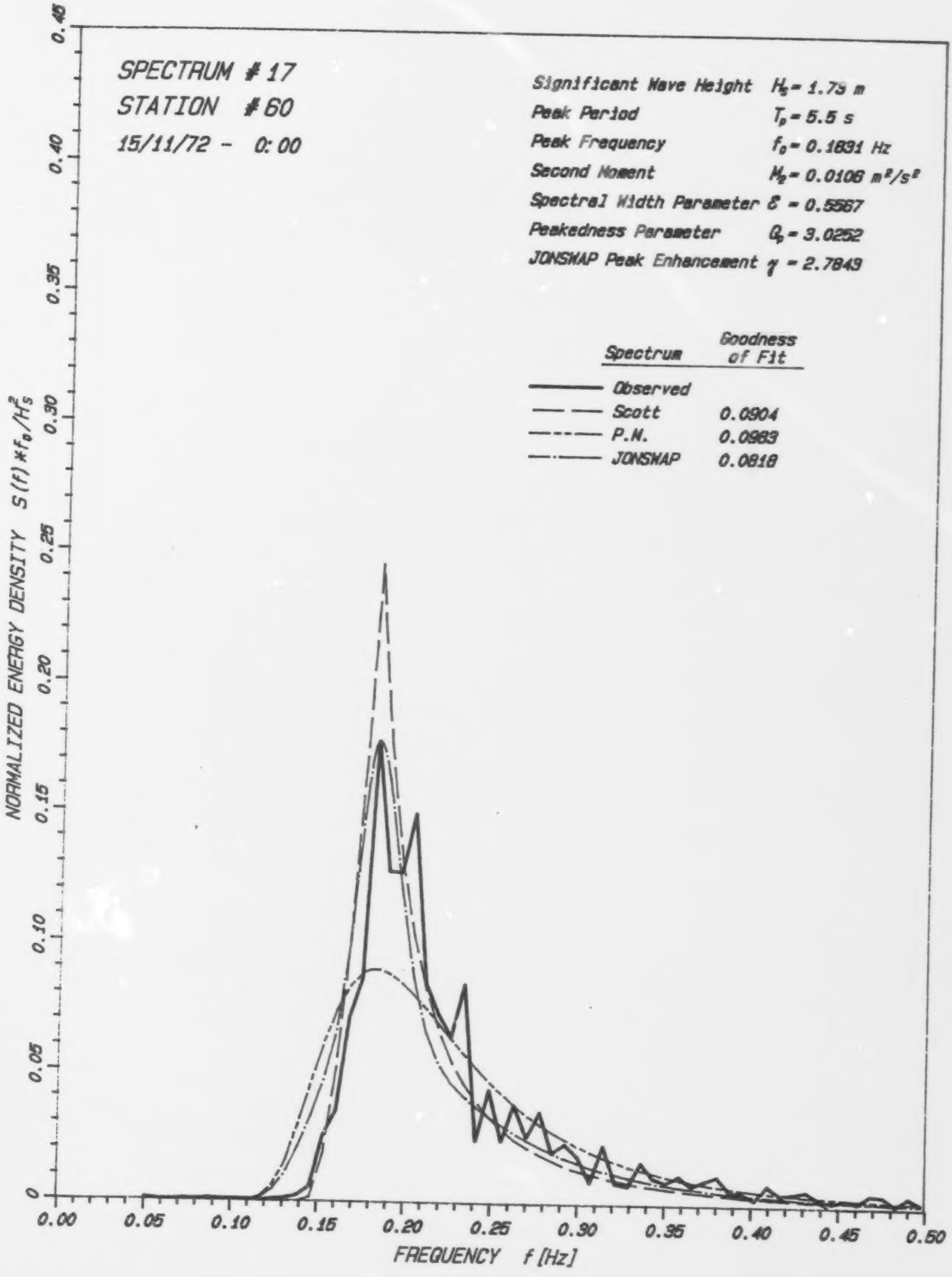

SPECTRUM # 12
STATION # 60
14/11/72 - 9:00
Significant Wave Height H_s = 2.15 m
Peak Period T_p = 5.5 s
Peak Frequency f_0 = 0.1831 Hz
Second Moment M_2 = 0.0144 m^2/s^2
Spectral Width Parameter ε = 0.5666
Peakedness Parameter Q_p = 3.7071
JONSWAP Peak Enhancement γ = 4.3331
Spectrum
Goodness of Fit
Observed
Scott 0.0642
P.N. 0.1405
JONSWAP 0.0798
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

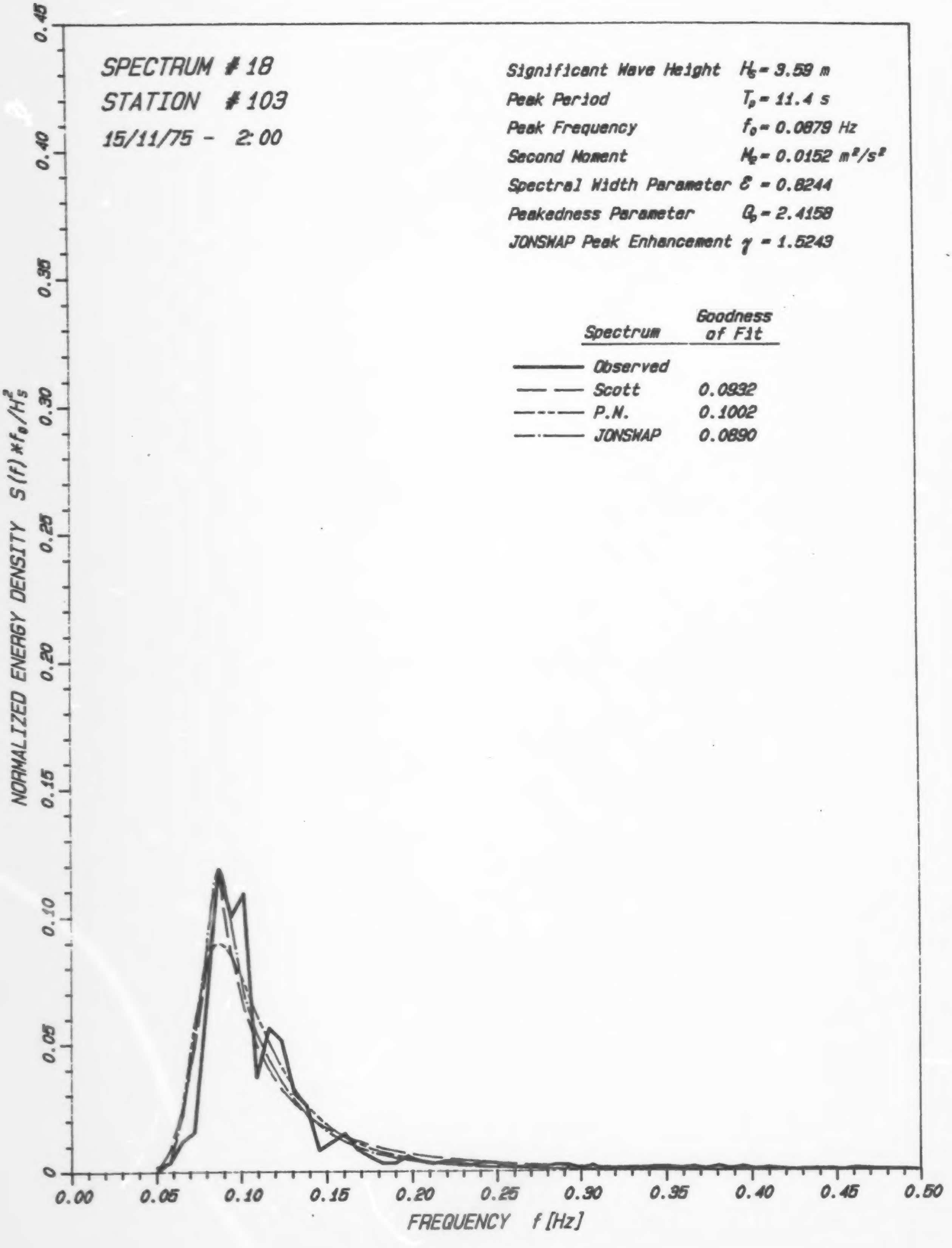

SPECTRUM # 13
STATION # 60
14/11/72 - 12:00
Significant Wave Height H_s = 2.49 m
Peak Period T_p = 5.5 s
Peak Frequency f_0 = 0.1831 Hz
Second Moment M_2 = 0.0172 m^2/s^2
Spectral Width Parameter ε = 0.6354
Peakedness Parameter Q_p = 3.3017
JONSWAP Peak Enhancement γ = 4.3839
Spectrum
Goodness of Fit
Observed
Scott 0.1183
P.N. 0.1545
JONSWAP 0.1180
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

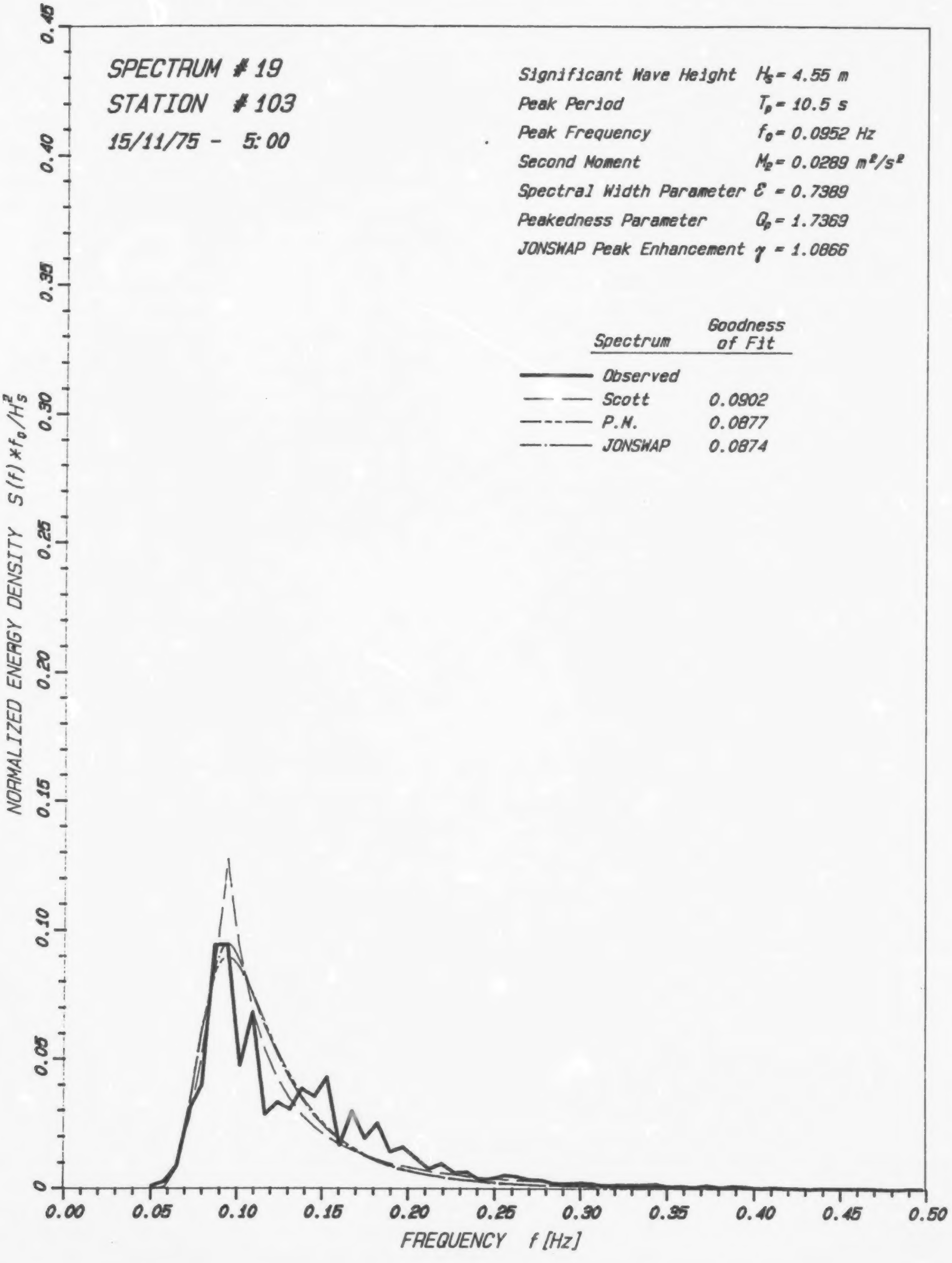

SPECTRUM # 14
STATION # 60
14/12/72 - 15:00
Significant Wave Height H_s = 2.98 m
Peak Period T_p = 5.9 s
Peak Frequency f_0 = 0.1685 Hz
Second Moment M_2 = 0.0236 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6161
Peakedness Parameter Q_p = 5.2467
JONSWAP Peak Enhancement γ = 8.7913
Spectrum
Goodness of Fit
Observed
Scott 0.1430
P.M. 0.2277
JONSWAP 0.1913
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

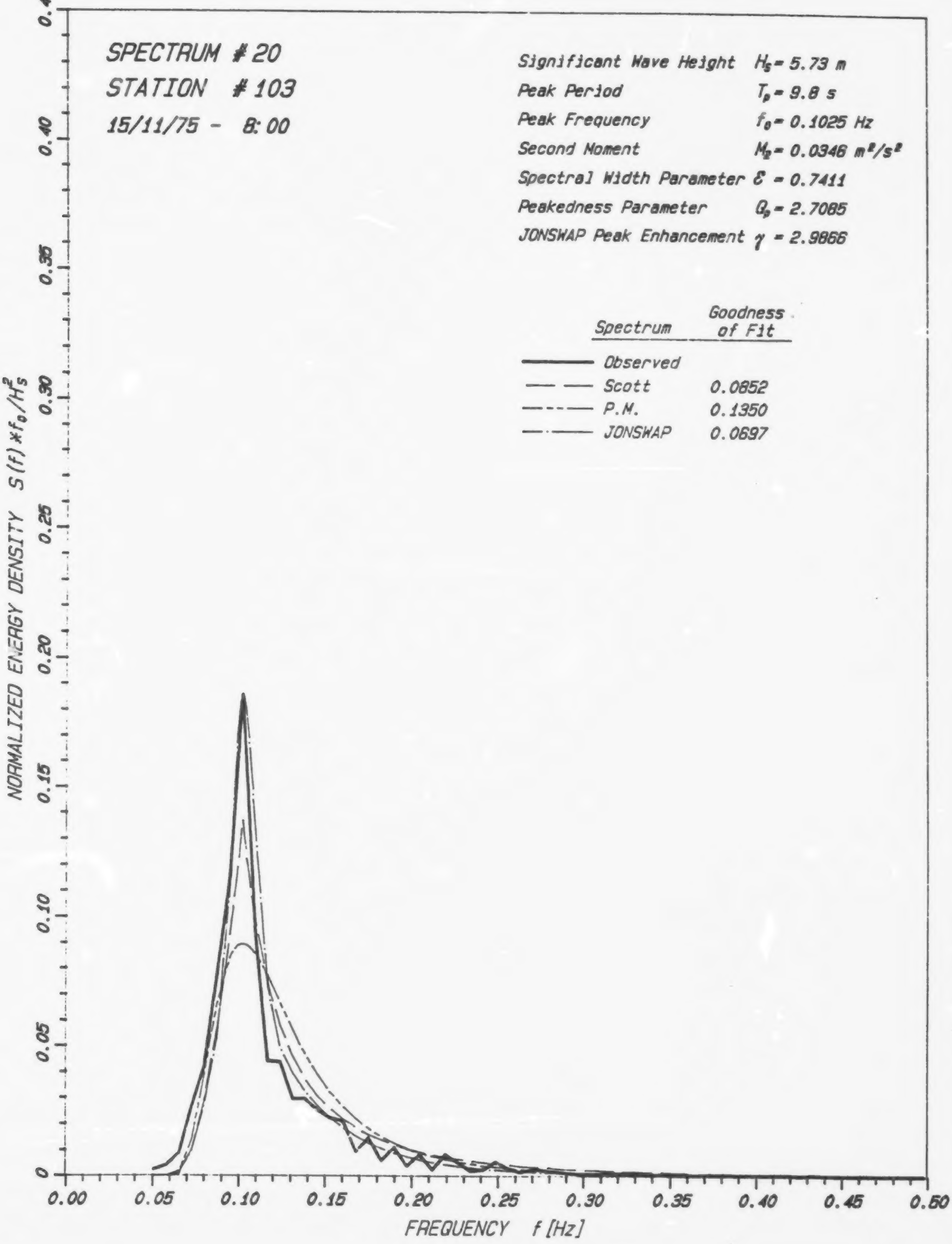

SPECTRUM # 15
STATION # 60
14/11/72 - 18:00
Significant Wave Height H_s = 2.81 m
Peak Period T_p = 5.9 s
Peak Frequency f_0 = 0.1685 Hz
Second Moment M_2 = 0.0197 m²/s²
Spectral Width Parameter ε = 0.5825
Peakedness Parameter Q_p = 4.1556
JONSWAP Peak Enhancement γ = 4.1978
Spectrum
Goodness of Fit
Observed
Scott 0.0718
P.M. 0.1641
JONSWAP 0.0660
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

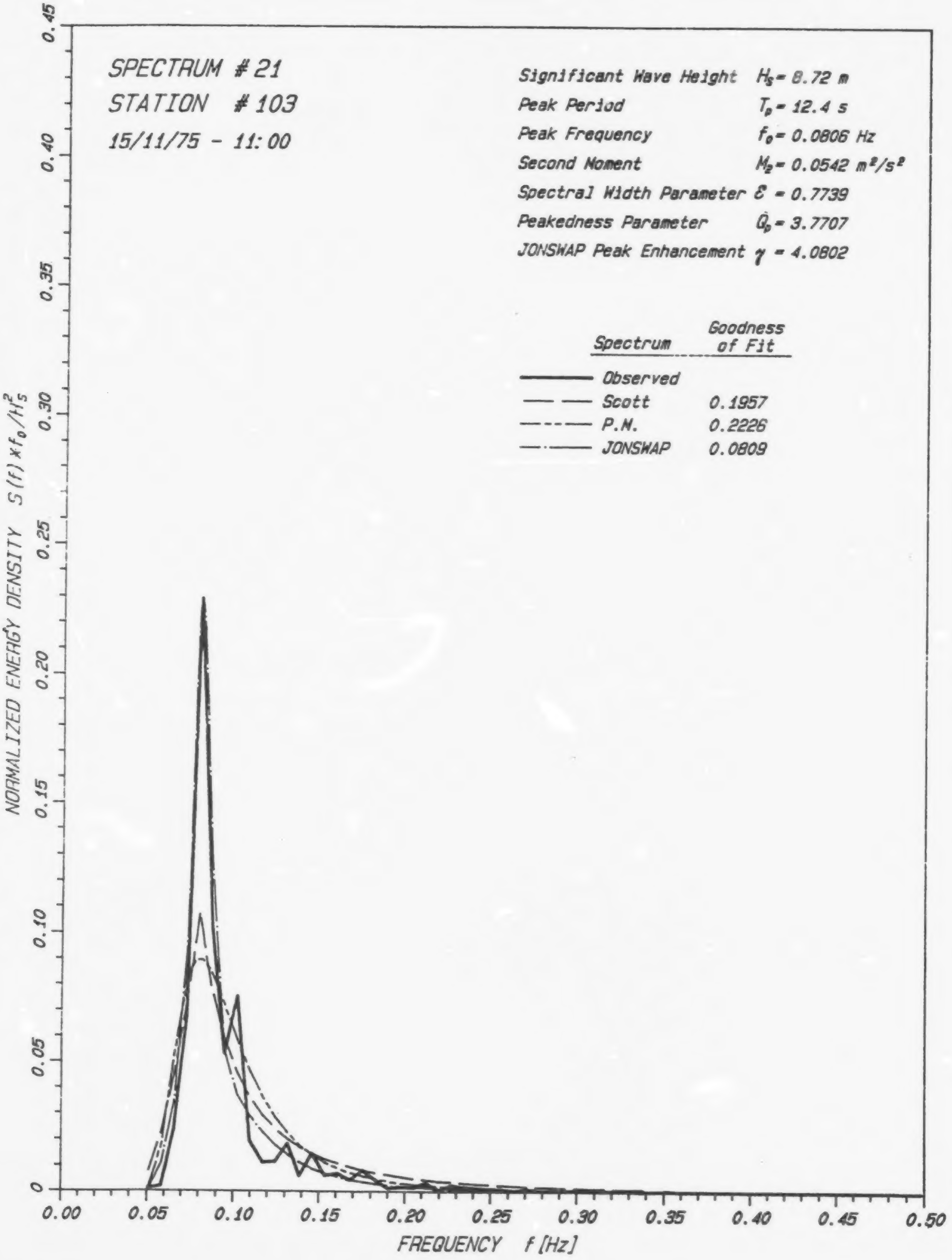

SPECTRUM # 16
STATION # 60
14/11/72 - 21:00
Significant Wave Height H_s = 2.36 m
Peak Period T_p = 5.9 s
Peak Frequency f_0 = 0.1685 Hz
Second Moment M_2 = 0.0158 m^2/s^2
Spectral Width Parameter ε = 0.5776
Peakedness Parameter Q_p = 4.0099
JONSWAP Peak Enhancement γ = 5.4142
Spectrum
Goodness of Fit
Observed
Scott 0.0966
P.N. 0.1666
JONSWAP 0.1329
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

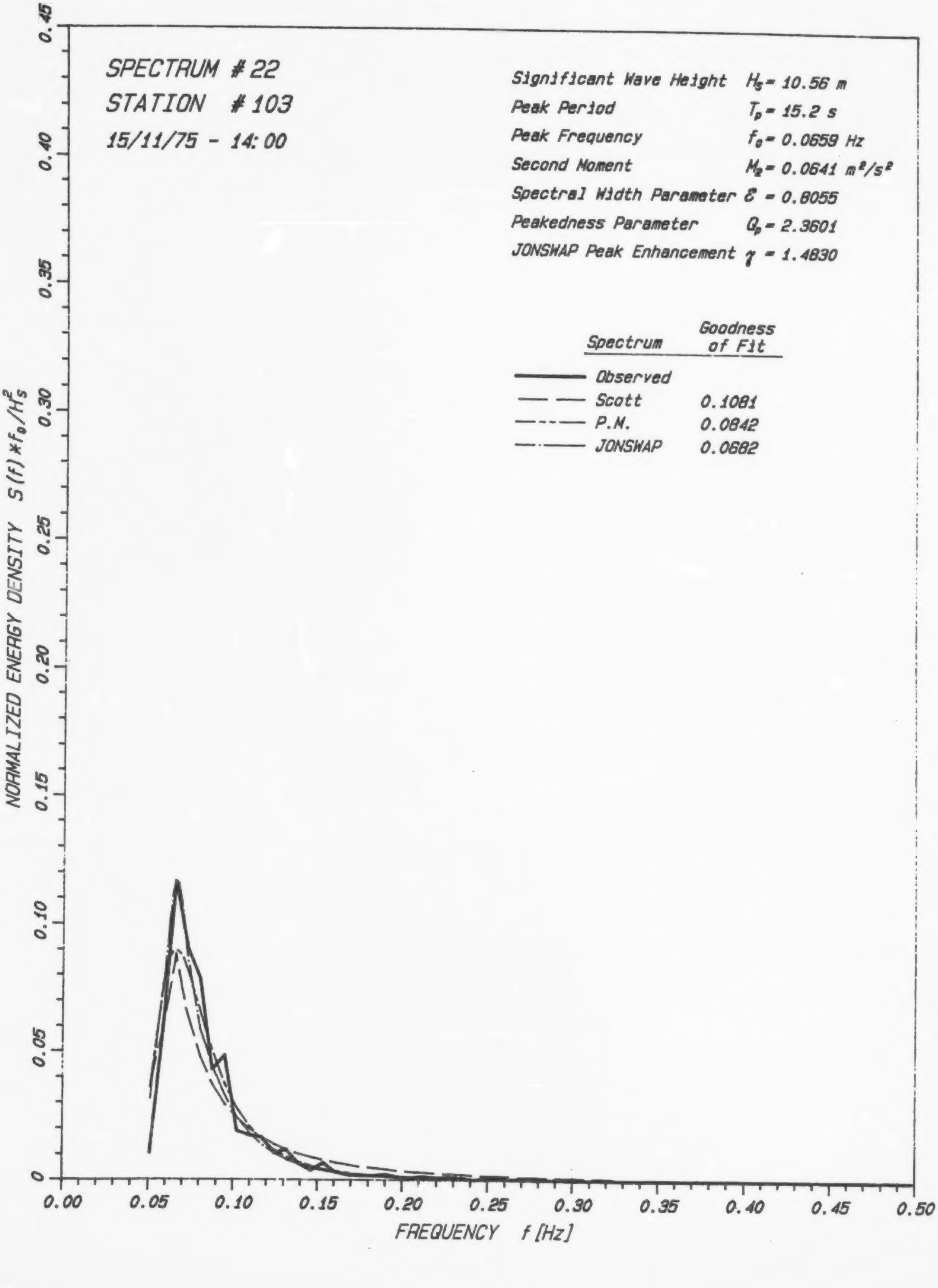

SPECTRUM # 17
STATION # 60
15/11/72 - 0:00
Significant Wave Height $H_s = 1.75$ m
Peak Period $T_p = 5.5$ s
Peak Frequency $f_0 = 0.1831$ Hz
Second Moment $M_2 = 0.0106$ m^2/s^2
Spectral Width Parameter $\mathcal{E} = 0.5567$
Peakedness Parameter $Q_p = 3.0252$
JONSWAP Peak Enhancement $\gamma = 2.7849$
Spectrum
Goodness of Fit
Observed
Scott 0.0904
P.N. 0.0983
JONSWAP 0.0818
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

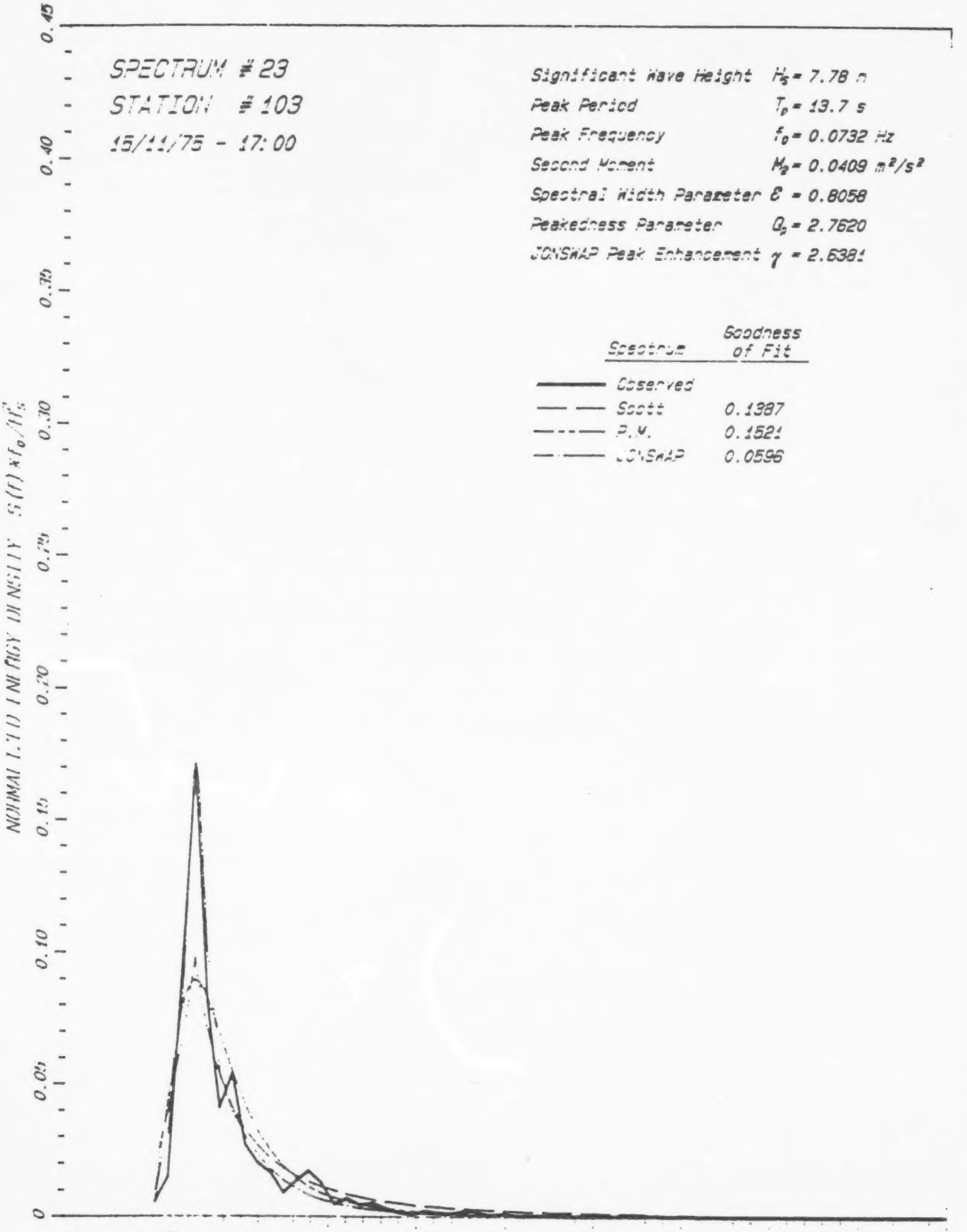

SPECTRUM # 18
STATION # 103
15/11/75 - 2:00
Significant Wave Height H_s = 3.59 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0152 m²/s²
Spectral Width Parameter ε = 0.8244
Peakedness Parameter Q_p = 2.4158
JONSWAP Peak Enhancement γ = 1.5243
Spectrum
Goodness of Fit
Observed
Scott 0.0932
P.N. 0.1002
JONSWAP 0.0890
NORMALIZED ENERGY DENSITY $S(f) \times f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

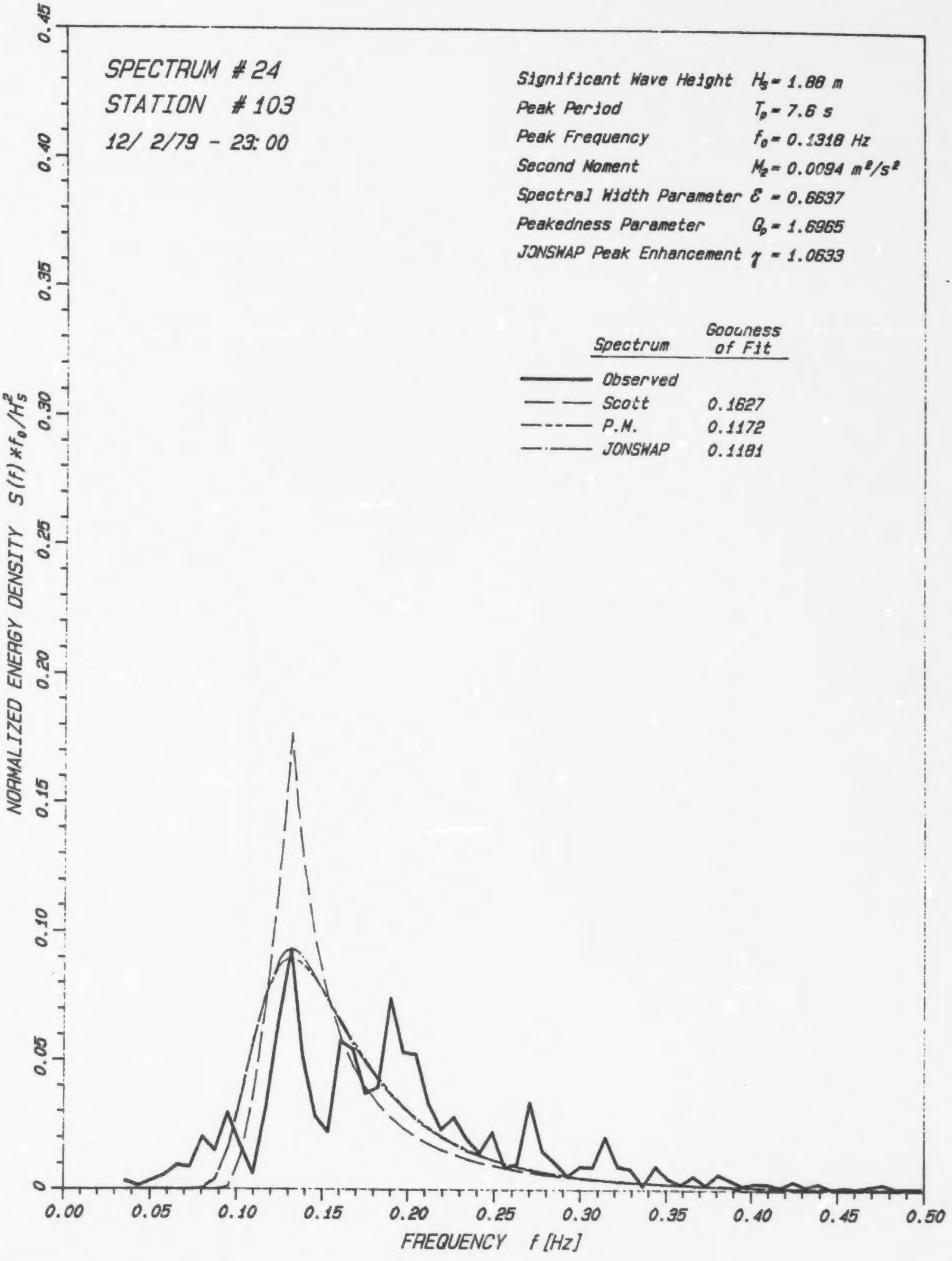

SPECTRUM # 19
STATION # 103
15/11/75 - 5:00
Significant Wave Height H_s = 4.55 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0289 m^2/s^2
Spectral Width Parameter ε = 0.7389
Peakedness Parameter Q_p = 1.7369
JONSWAP Peak Enhancement γ = 1.0866
Spectrum
Goodness of Fit
Observed
Scott 0.0902
P.M. 0.0877
JONSWAP 0.0874
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

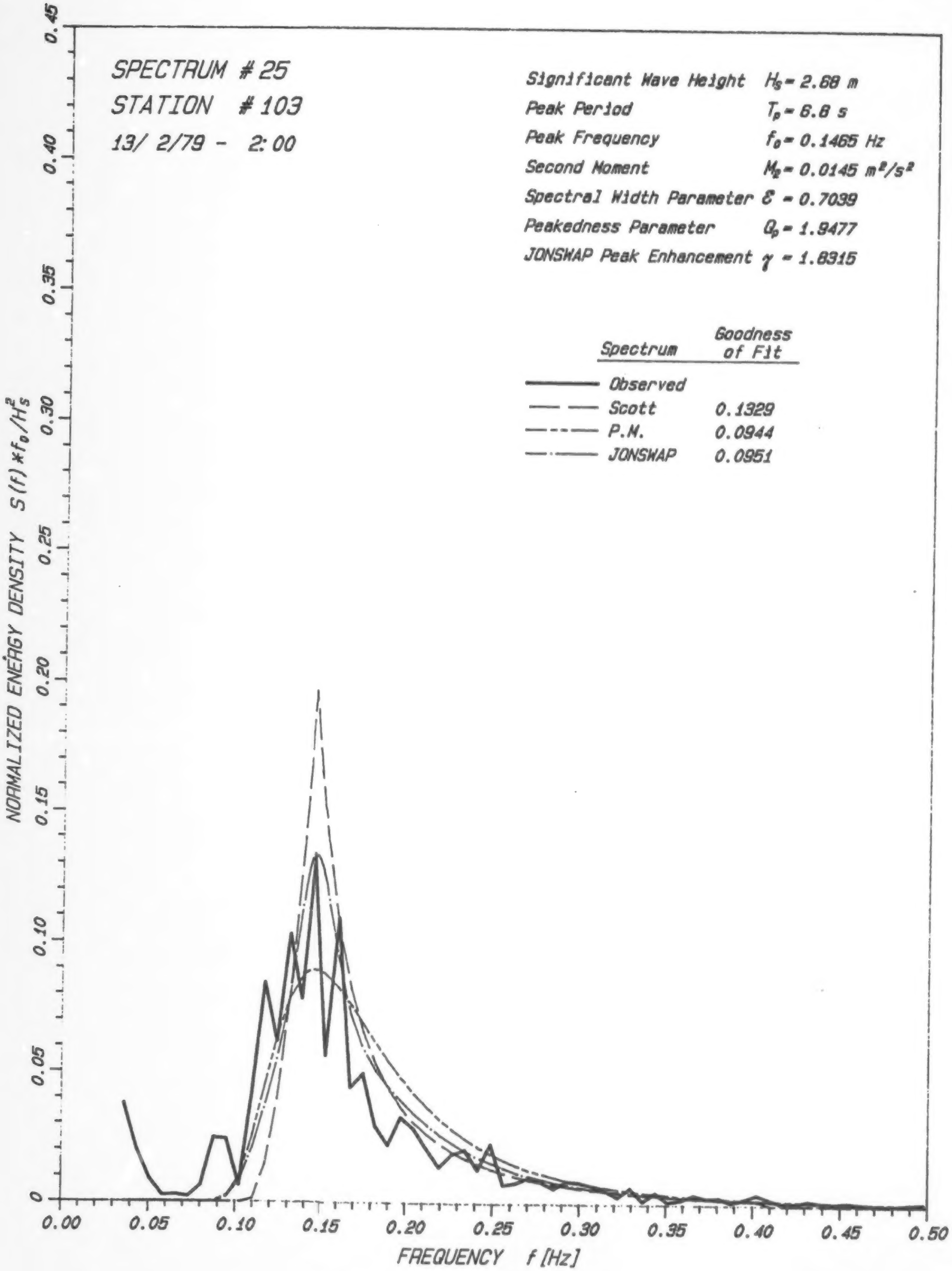

SPECTRUM # 20
STATION # 103
15/11/75 - 8:00
Significant Wave Height $H_s = 5.73$ m
Peak Period $T_p = 9.8$ s
Peak Frequency $f_0 = 0.1025$ Hz
Second Moment $M_2 = 0.0346$ m²/s²
Spectral Width Parameter $\mathcal{E} = 0.7411$
Peakedness Parameter $Q_p = 2.7085$
JONSWAP Peak Enhancement $\gamma = 2.9866$
Spectrum
Goodness of Fit
Observed
Scott 0.0852
P.M. 0.1350
JONSWAP 0.0697
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

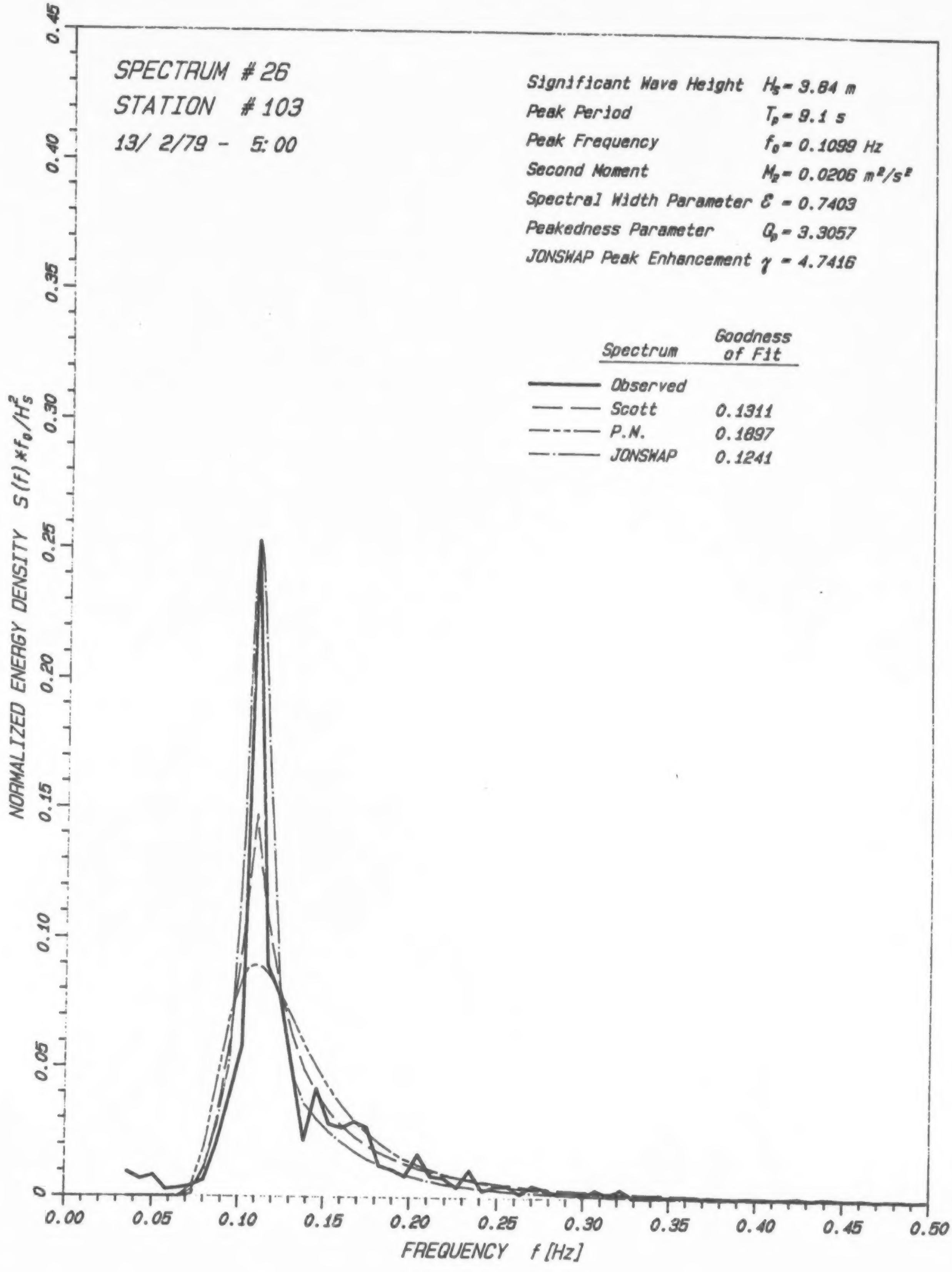

SPECTRUM # 21
STATION # 103
15/11/75 - 11:00
Significant Wave Height H_s = 8.72 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0542 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.7739
Peakedness Parameter $\hat{Q}_p$ = 3.7707
JONSWAP Peak Enhancement γ = 4.0802
Spectrum
Goodness of Fit
Observed
Scott 0.1957
P.M. 0.2226
JONSWAP 0.0809
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

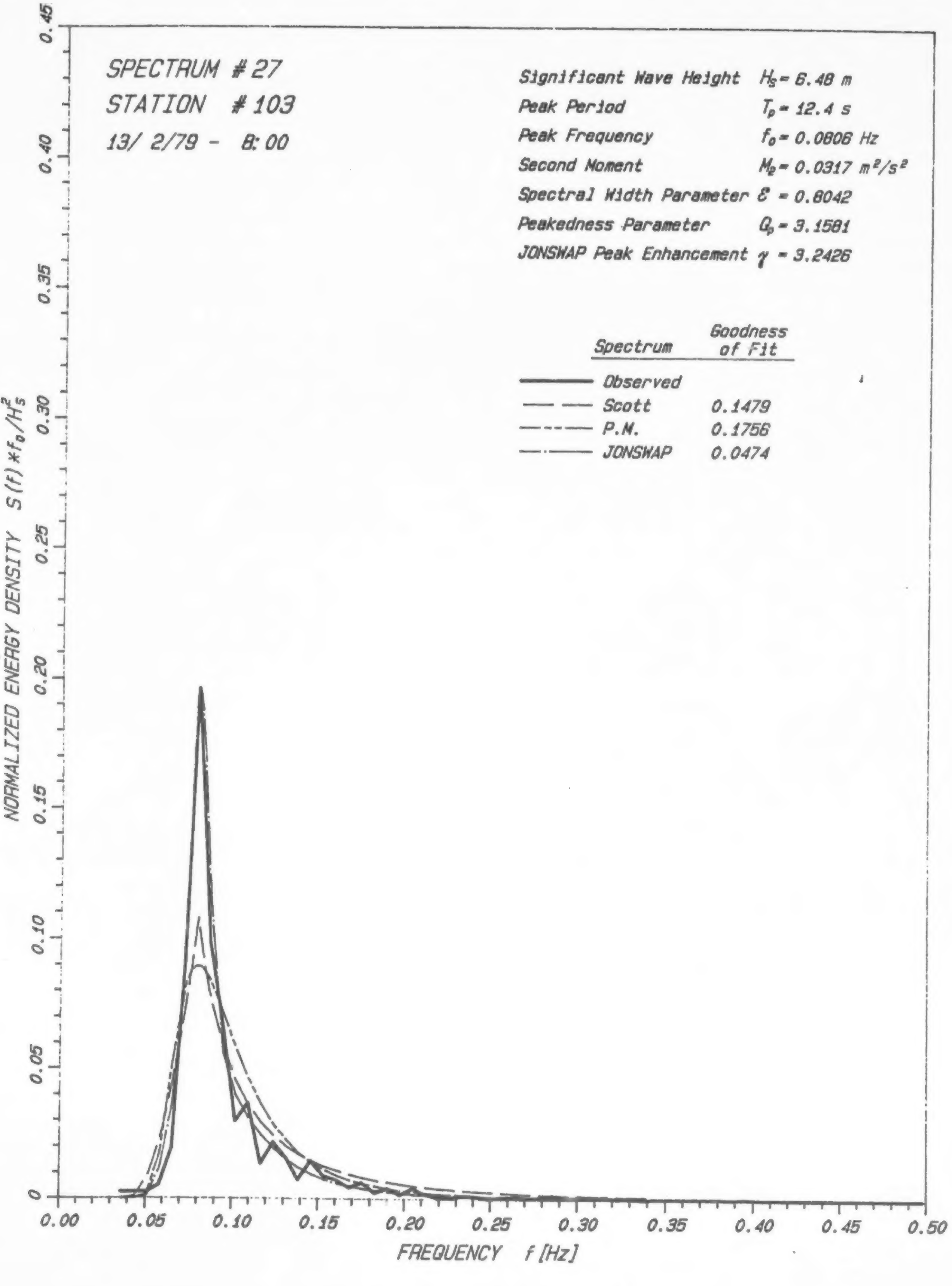

SPECTRUM # 22
STATION # 103
15/11/75 - 14:00
Significant Wave Height H_s = 10.56 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0641 m^2/s^2
Spectral Width Parameter ε = 0.8055
Peakedness Parameter Q_p = 2.3601
JONSWAP Peak Enhancement γ = 1.4830
Spectrum
Goodness of Fit
Observed
Scott 0.1081
P.M. 0.0842
JONSWAP 0.0682
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

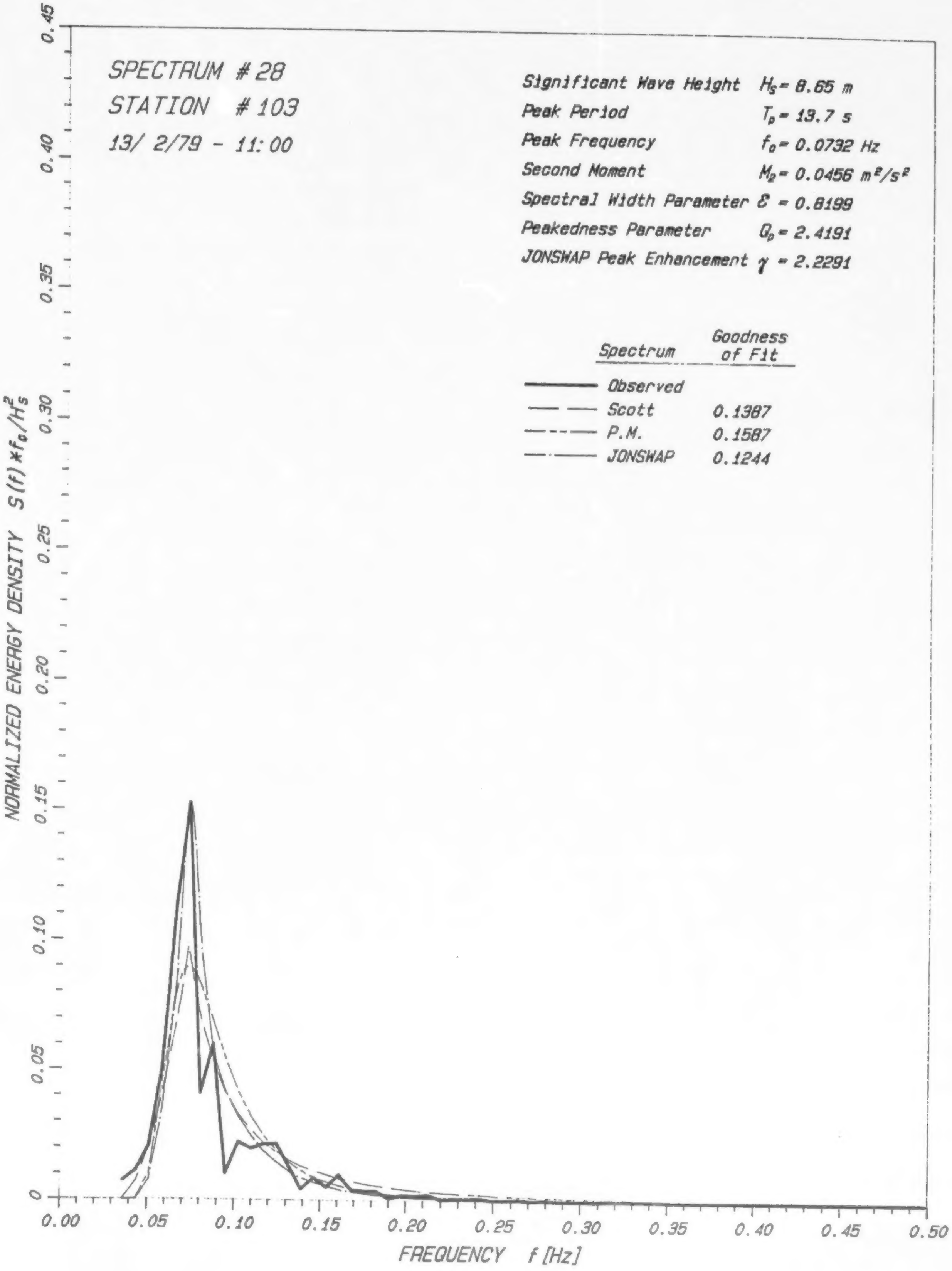

SPECTRUM # 23
STATION # 103
15/11/75 - 17:00
Significant Wave Height H_s = 7.78 m
Peak Period T_p = 13.7 s
Peak Frequency f_0 = 0.0732 Hz
Second Moment M_2 = 0.0409 m²/s²
Spectral Width Parameter ε = 0.8058
Peakedness Parameter Q_p = 2.7620
JONSWAP Peak Enhancement γ = 2.6381
Spectrum
Goodness of Fit
Observed
Scott 0.1387
P.M. 0.1521
JONSWAP 0.0596
NORMALIZED ENERGY DENSITY $S(f) \times f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f (Hz)

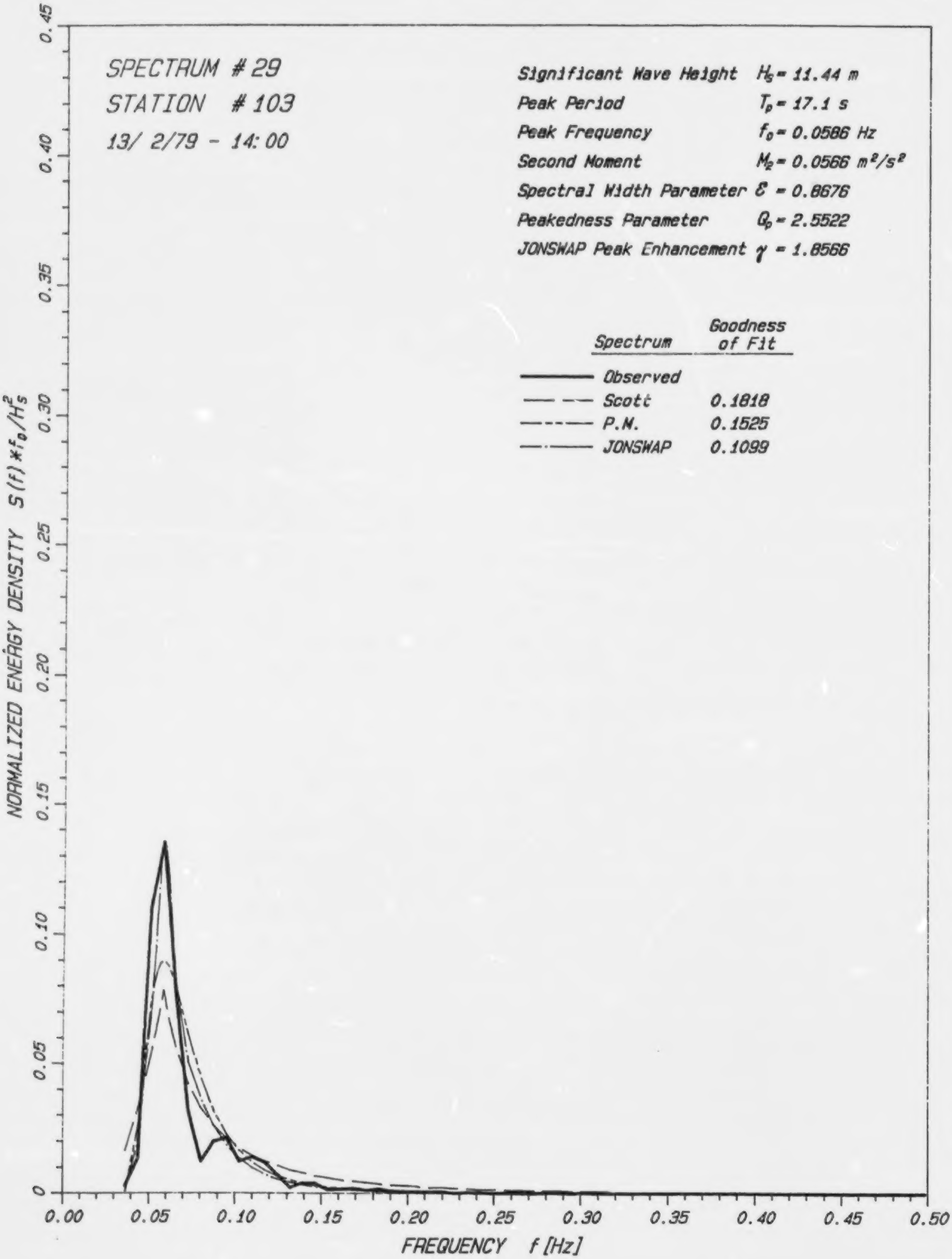

SPECTRUM # 24
STATION # 103
12/ 2/79 - 23: 00
Significant Wave Height H_s = 1.88 m
Peak Period T_p = 7.6 s
Peak Frequency f_0 = 0.1318 Hz
Second Moment M_2 = 0.0094 m^2/s^2
Spectral Width Parameter ε = 0.6637
Peakedness Parameter Q_p = 1.6965
JONSWAP Peak Enhancement γ = 1.0633
Spectrum
Goodness of Fit
Observed
Scott 0.1627
P.M. 0.1172
JONSWAP 0.1181
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

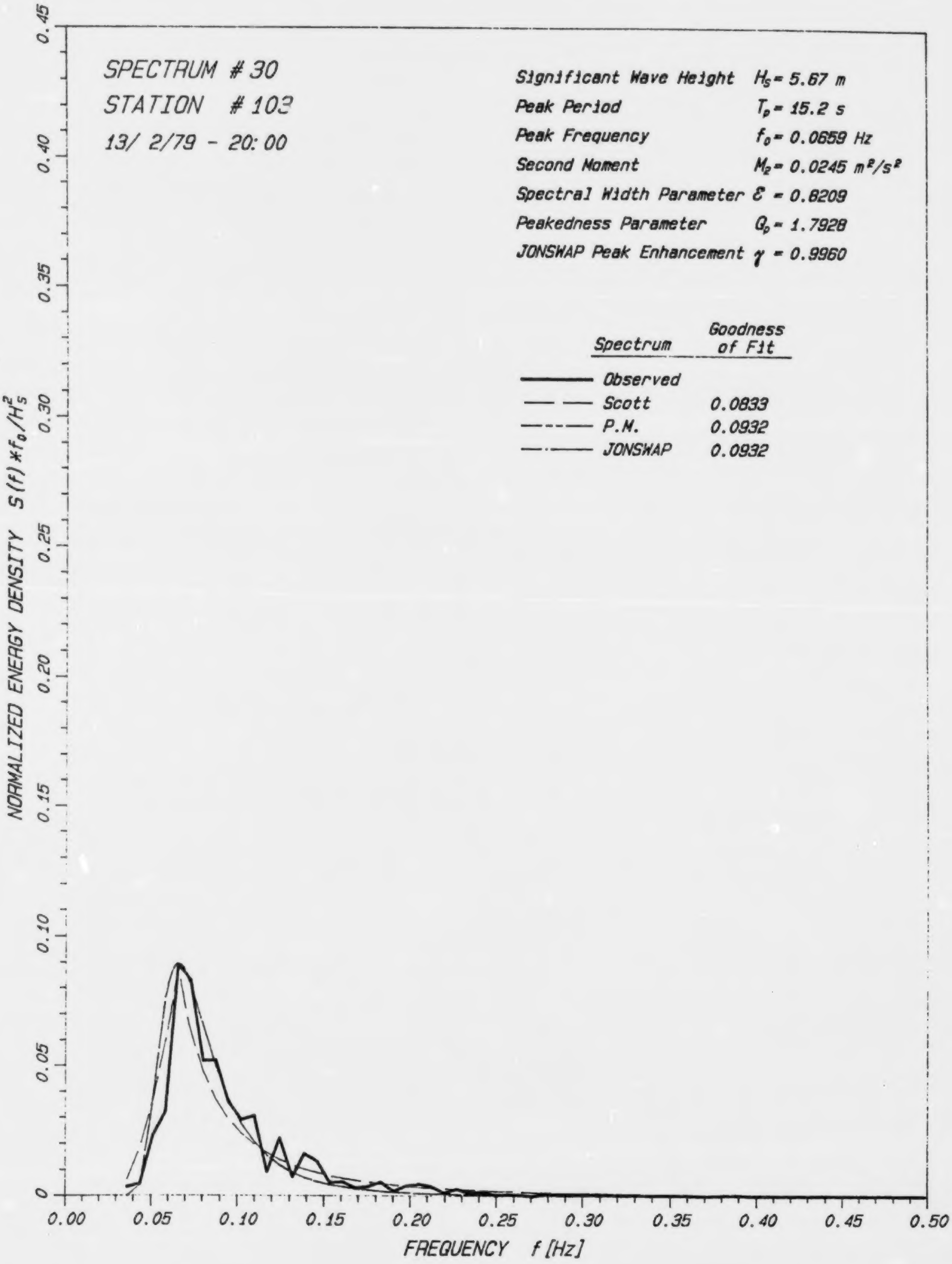

SPECTRUM # 25
STATION # 103
13/ 2/79 - 2:00
Significant Wave Height H_s = 2.68 m
Peak Period T_p = 6.8 s
Peak Frequency f_0 = 0.1465 Hz
Second Moment M_2 = 0.0145 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.7039
Peakedness Parameter Q_p = 1.9477
JONSWAP Peak Enhancement γ = 1.8315
Spectrum
Goodness of Fit
Observed
Scott 0.1329
P.M. 0.0944
JONSWAP 0.0951
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

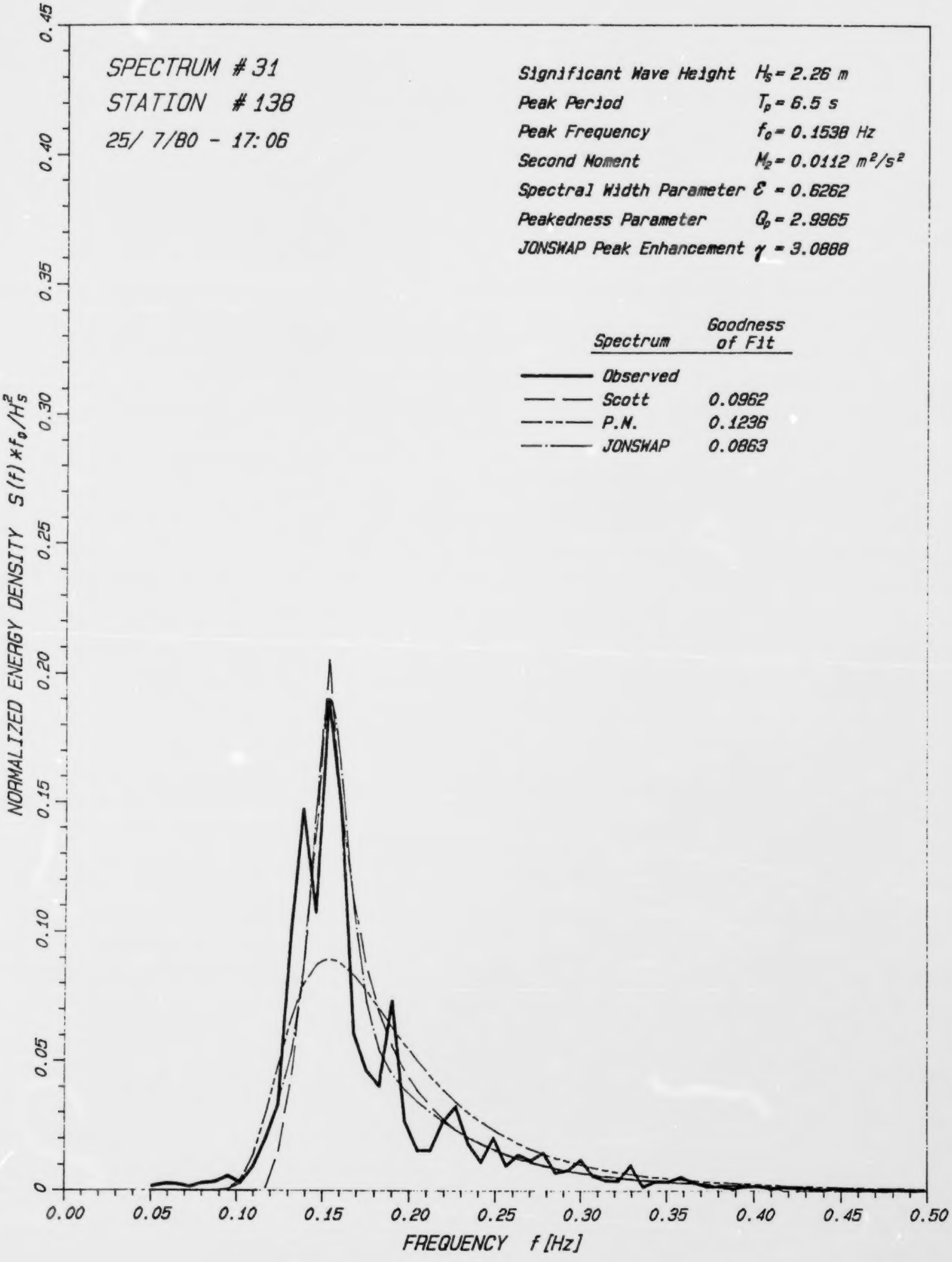

SPECTRUM # 26
STATION # 103
13/ 2/79 - 5: 00
Significant Wave Height H_s = 3.84 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0206 m^2/s^2
Spectral Width Parameter ε = 0.7403
Peakedness Parameter Q_p = 3.3057
JONSWAP Peak Enhancement γ = 4.7416
Spectrum
Goodness of Fit
Observed
Scott 0.1311
P.N. 0.1897
JONSWAP 0.1241
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

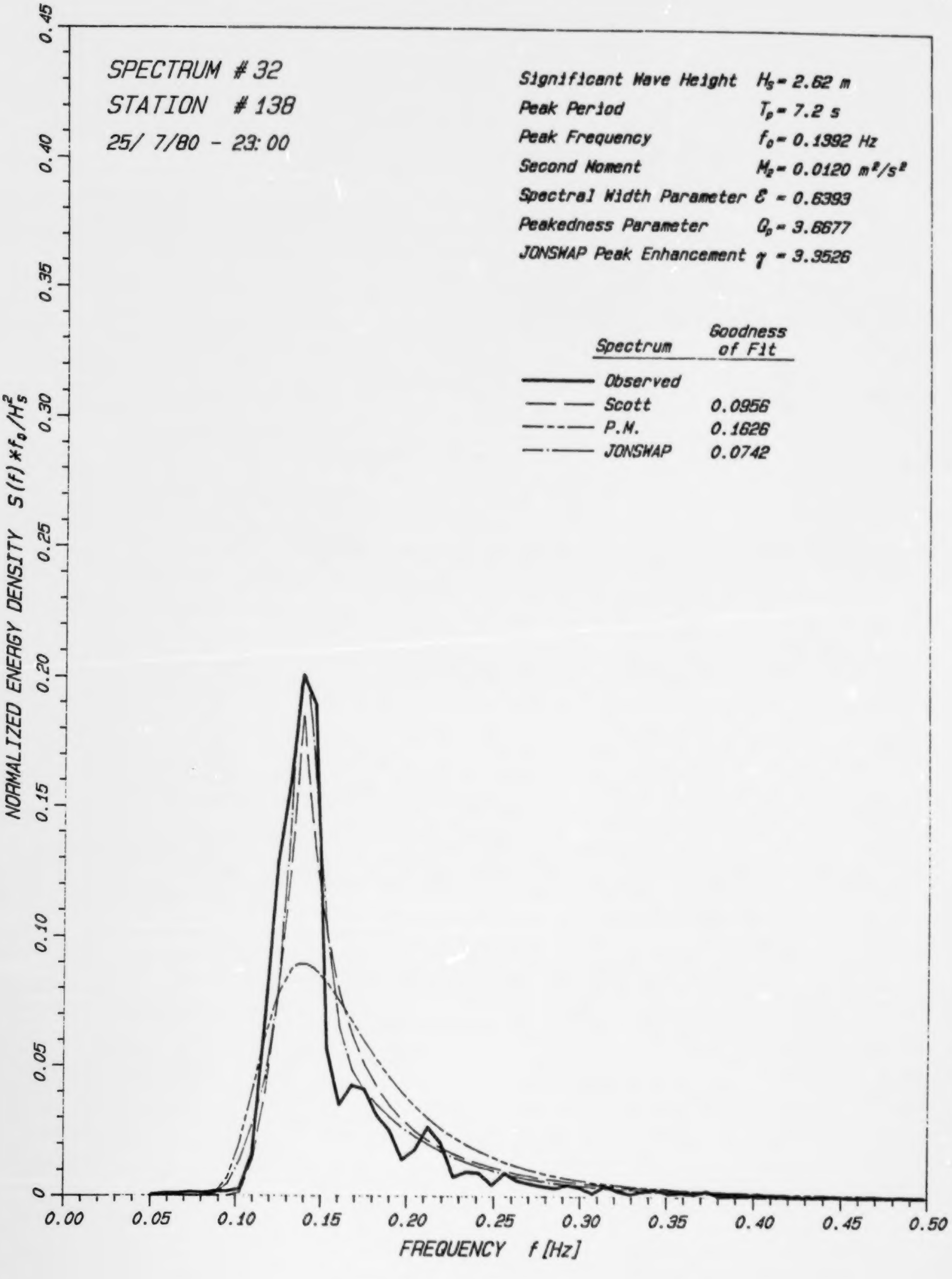

SPECTRUM # 27
STATION # 103
13/ 2/79 - 8:00
Significant Wave Height H_s = 6.48 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0317 m^2/s^2
Spectral Width Parameter ε = 0.8042
Peakedness Parameter Q_p = 3.1581
JONSWAP Peak Enhancement γ = 3.2426
Spectrum
Goodness of Fit
Observed
Scott 0.1479
P.M. 0.1756
JONSWAP 0.0474
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

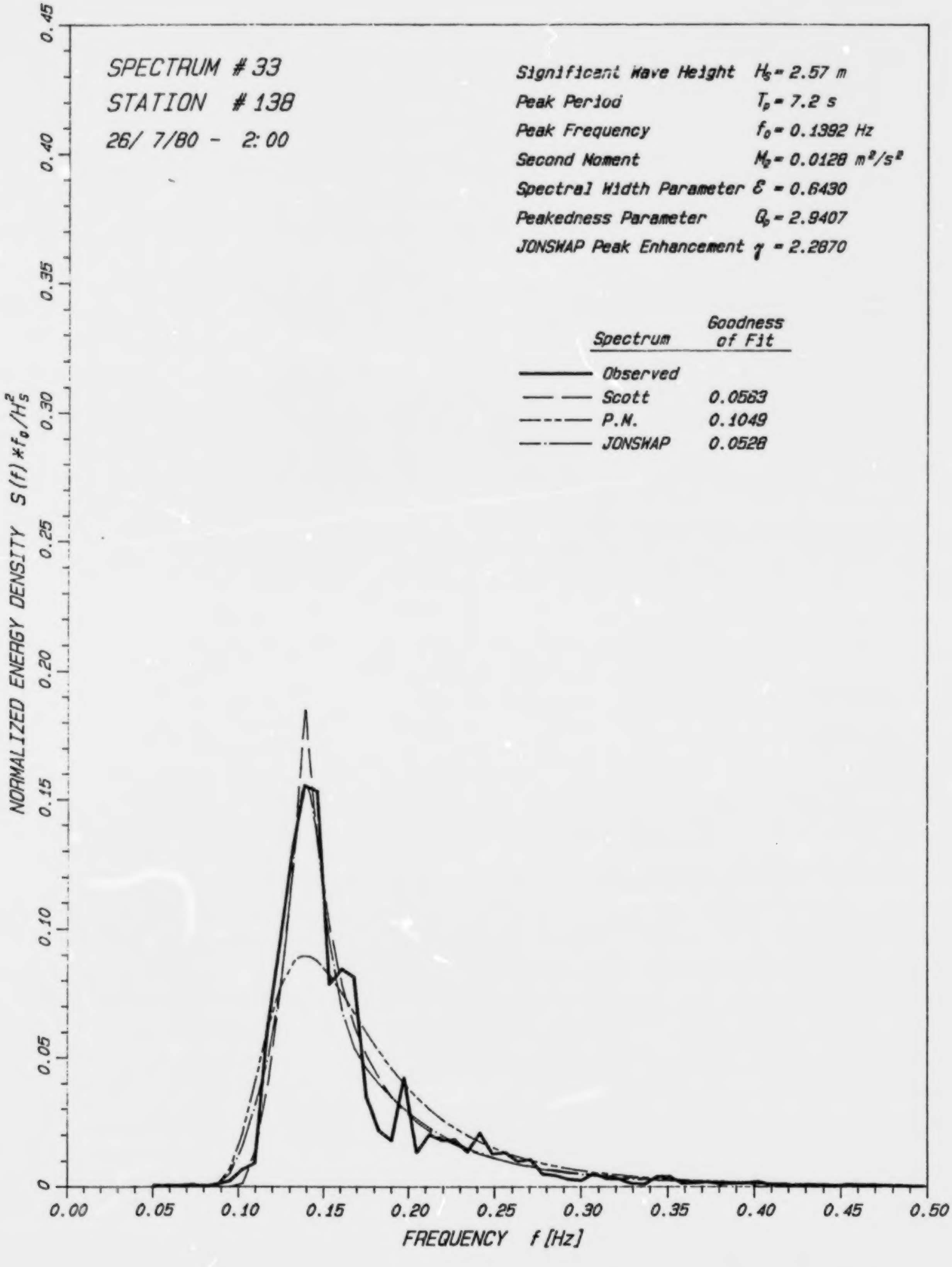

SPECTRUM # 28
STATION # 103
13/ 2/79 - 11:00
Significant Wave Height H_s = 8.65 m
Peak Period T_p = 13.7 s
Peak Frequency f_0 = 0.0732 Hz
Second Moment M_2 = 0.0456 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.8199
Peakedness Parameter Q_p = 2.4191
JONSWAP Peak Enhancement γ = 2.2291
Spectrum
Goodness of Fit
Observed
Scott 0.1387
P.M. 0.1587
JONSWAP 0.1244
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]

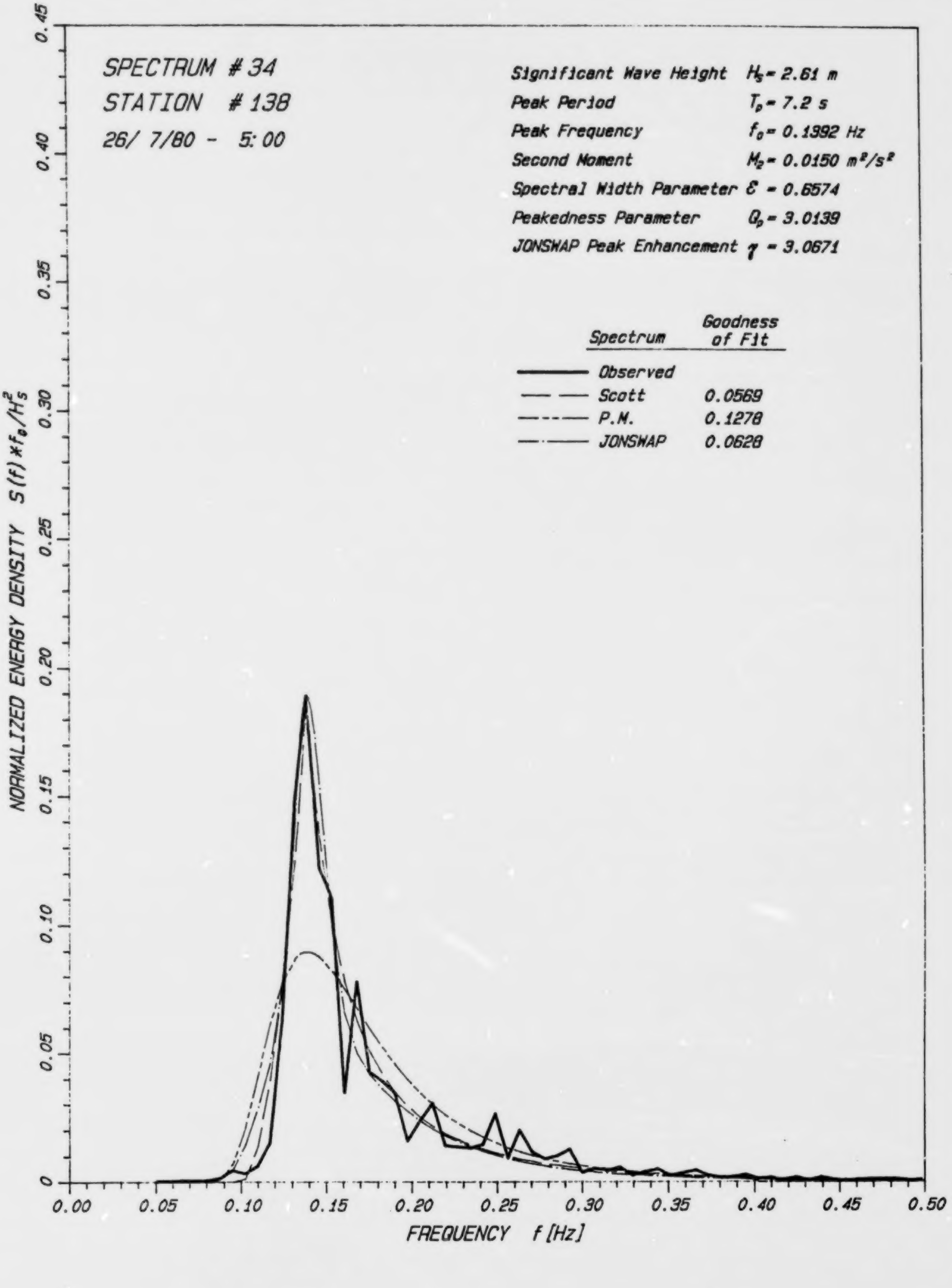

SPECTRUM # 29
STATION # 103
13/ 2/79 - 14: 00
Significant Wave Height H_s = 11.44 m
Peak Period T_p = 17.1 s
Peak Frequency f_0 = 0.0586 Hz
Second Moment M_2 = 0.0566 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.8676
Peakedness Parameter Q_p = 2.5522
JONSWAP Peak Enhancement γ = 1.8566
Spectrum
Goodness of Fit
Observed
Scott 0.1818
P.M. 0.1525
JONSWAP 0.1099
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

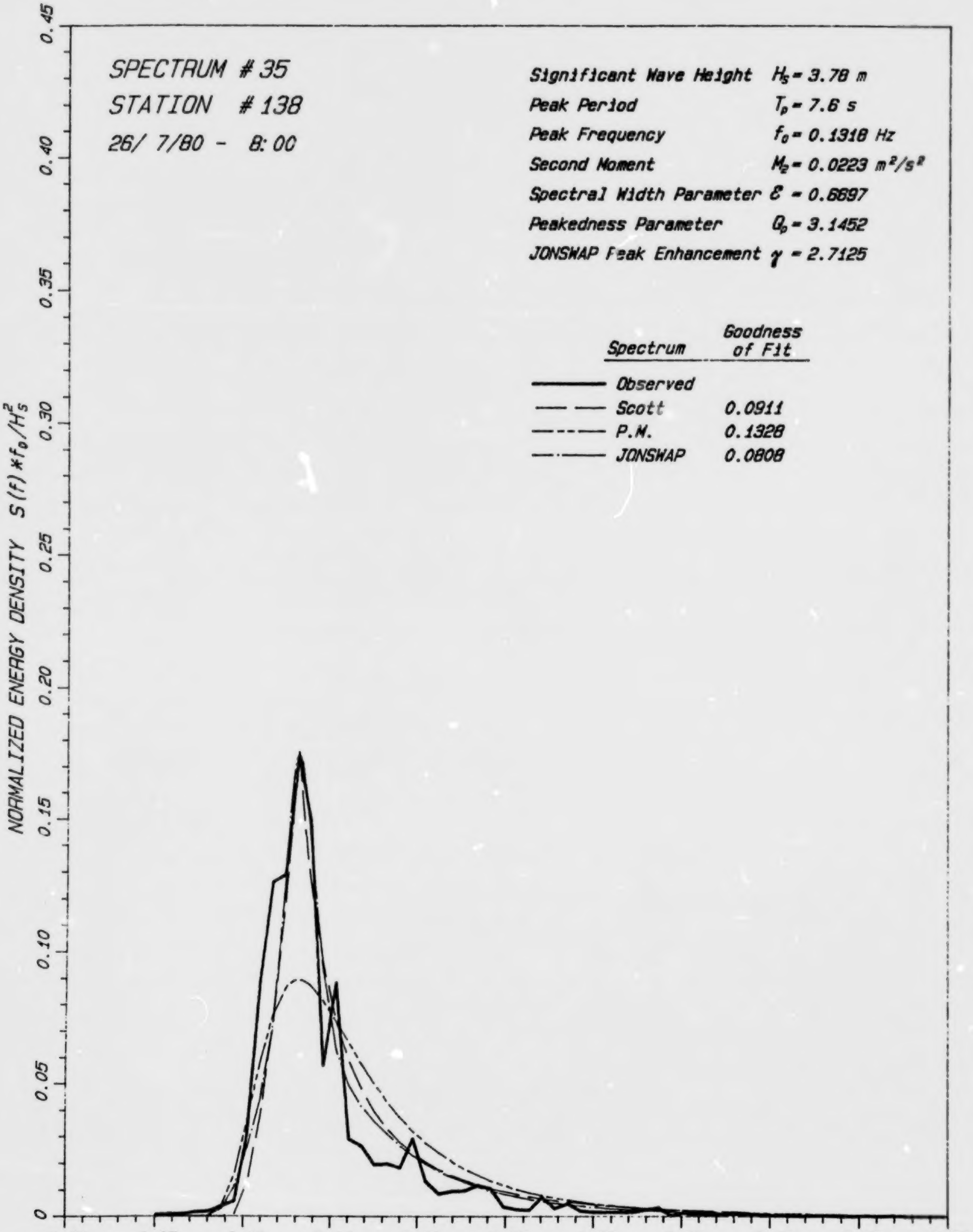

SPECTRUM # 30
STATION # 103
13/ 2/79 - 20: 00
Significant Wave Height H_S = 5.67 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0245 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.8209
Peakedness Parameter Q_p = 1.7928
JONSWAP Peak Enhancement γ = 0.9960
Spectrum
Goodness of Fit
Observed
Scott 0.0833
P.M. 0.0932
JONSWAP 0.0932
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_S^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

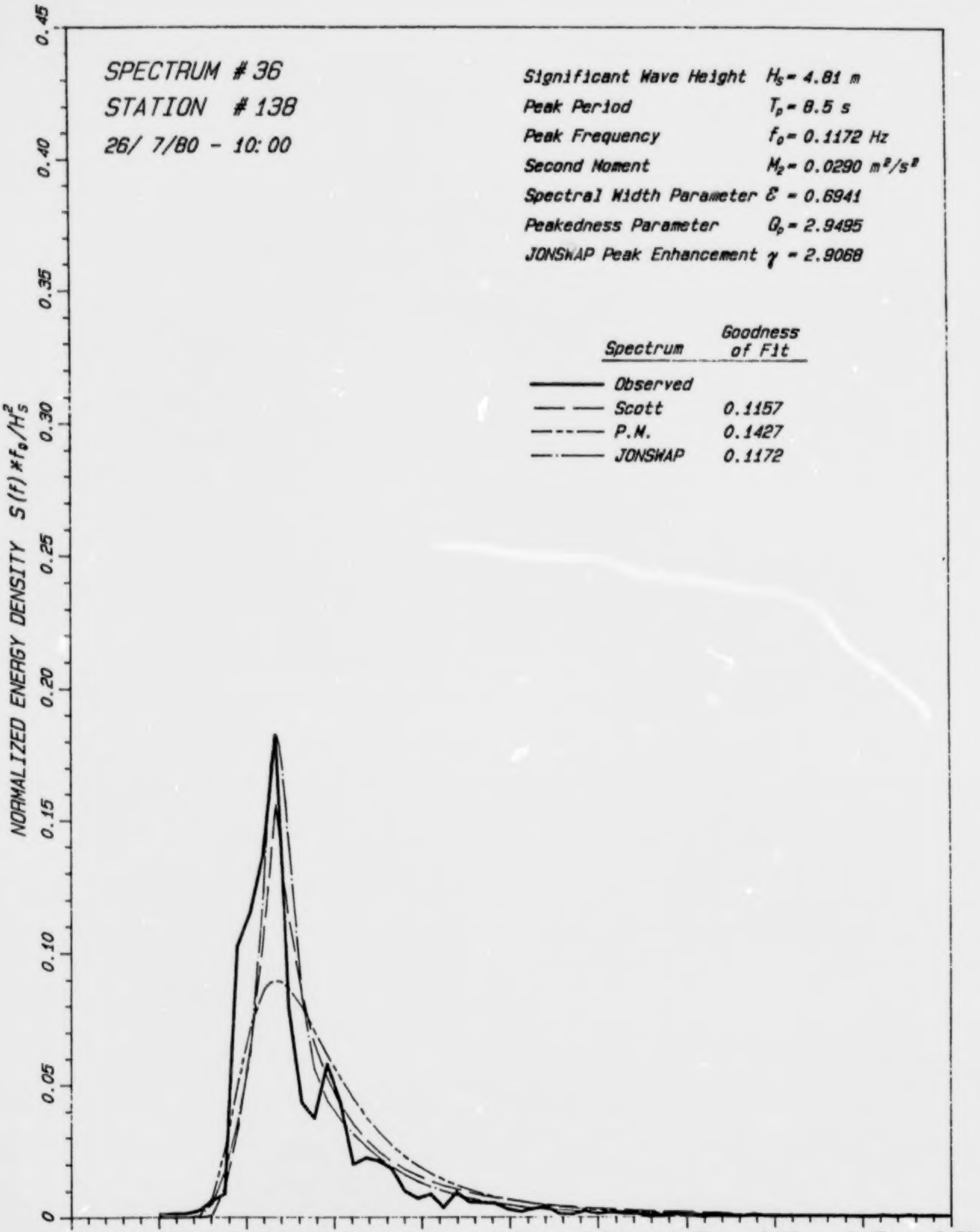

SPECTRUM # 31
STATION # 138
25/ 7/80 - 17: 06
Significant Wave Height $H_s = 2.26$ m
Peak Period $T_p = 6.5$ s
Peak Frequency $f_0 = 0.1538$ Hz
Second Moment $M_2 = 0.0112$ m^2/s^2
Spectral Width Parameter $\mathcal{E} = 0.6262$
Peakedness Parameter $Q_p = 2.9965$
JONSWAP Peak Enhancement $\gamma = 3.0888$
Spectrum
Goodness of Fit
Observed
Scott 0.0962
P.M. 0.1236
JONSWAP 0.0863
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

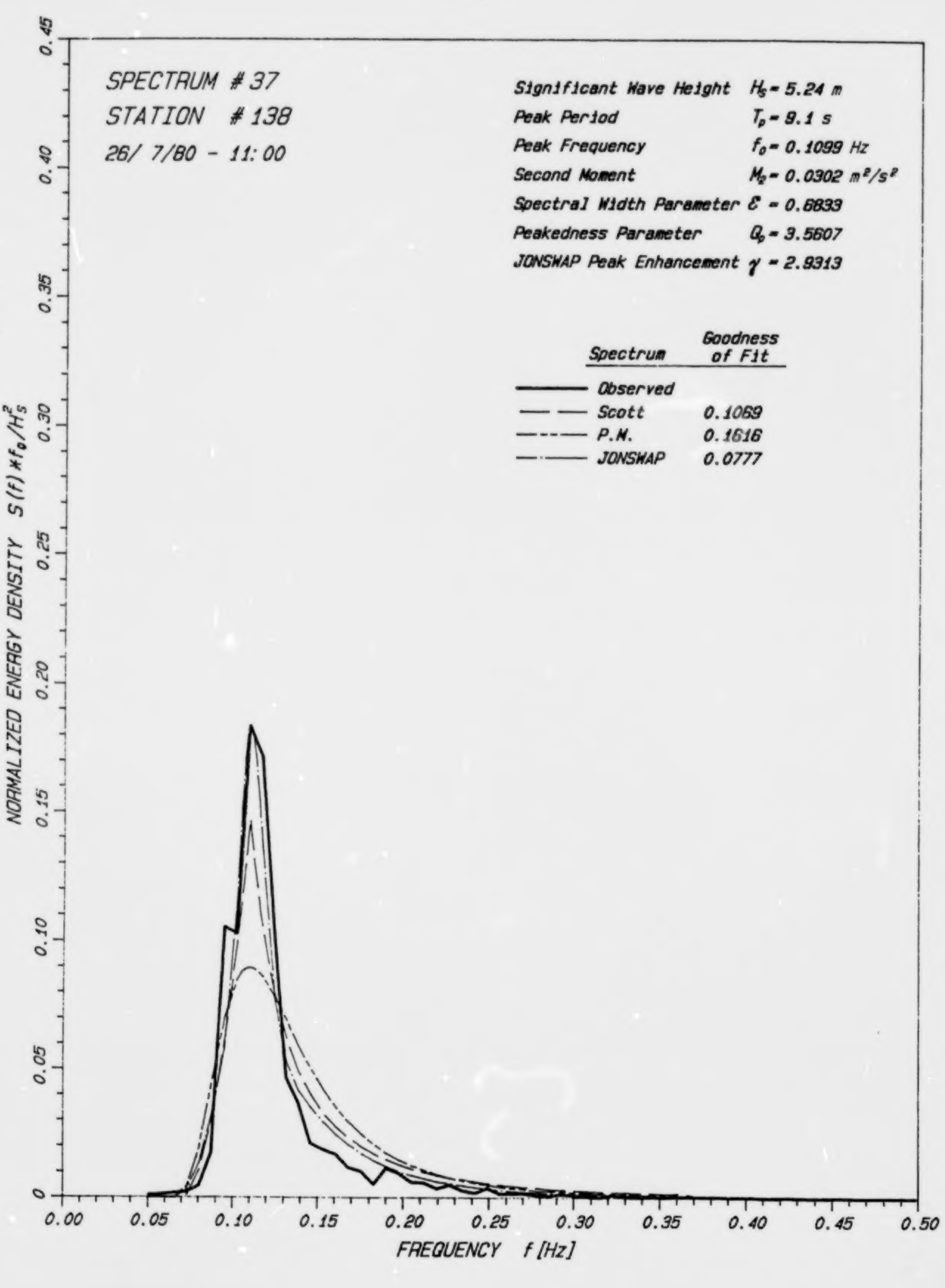

SPECTRUM # 32
STATION # 138
25/ 7/80 - 23: 00
Significant Wave Height H_s = 2.62 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0120 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6393
Peakedness Parameter Q_p = 3.6677
JONSWAP Peak Enhancement γ = 3.3526
Spectrum
Goodness of Fit
Observed
Scott 0.0956
P.M. 0.1626
JONSWAP 0.0742
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

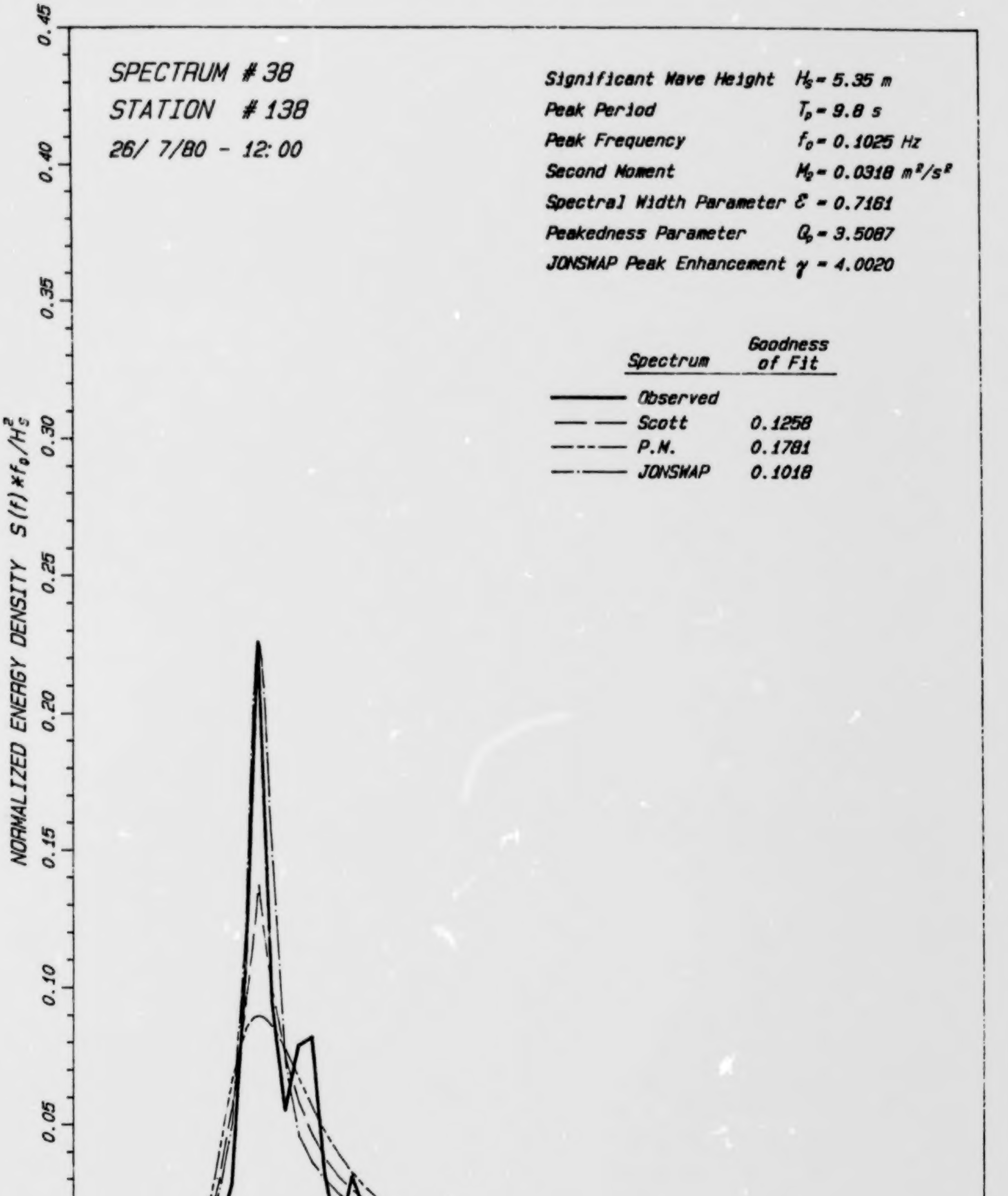

SPECTRUM # 33
STATION # 138
26/ 7/80 - 2: 00
Significant Wave Height H_s = 2.57 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0128 m²/s²
Spectral Width Parameter ε = 0.6430
Peakedness Parameter Q_p = 2.9407
JONSWAP Peak Enhancement γ = 2.2870
Spectrum
Goodness of Fit
Observed
Scott 0.0563
P.M. 0.1049
JONSWAP 0.0528
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

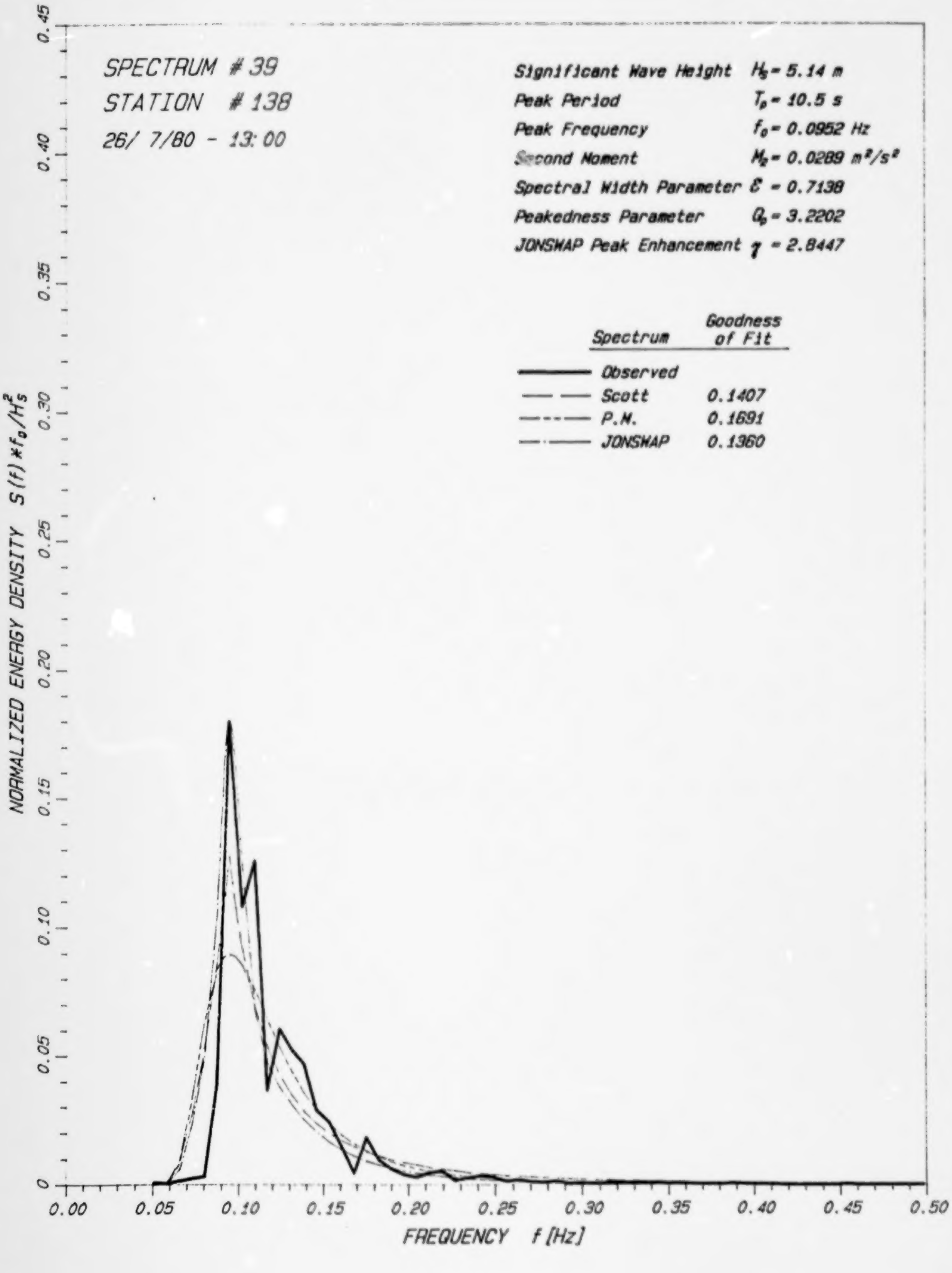

SPECTRUM # 34
STATION # 138
26/ 7/80 - 5: 00
Significant Wave Height H_s = 2.61 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0150 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.6574
Peakedness Parameter Q_p = 3.0139
JONSWAP Peak Enhancement γ = 3.0671
Spectrum
Goodness of Fit
Observed
Scott 0.0569
P.M. 0.1278
JONSWAP 0.0628
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 35
STATION # 138
26/ 7/80 - 8: 00
Significant Wave Height H_s = 3.78 m
Peak Period T_p = 7.6 s
Peak Frequency f_0 = 0.1318 Hz
Second Moment M_2 = 0.0223 m^2/s^2
Spectral Width Parameter ε = 0.6697
Peakedness Parameter Q_p = 3.1452
JONSWAP Peak Enhancement γ = 2.7125
Spectrum
Goodness of Fit
Observed
Scott 0.0911
P.M. 0.1328
JONSWAP 0.0808
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 36
STATION # 138
26/ 7/80 - 10:00
Significant Wave Height H_s = 4.81 m
Peak Period T_p = 8.5 s
Peak Frequency f_0 = 0.1172 Hz
Second Moment M_2 = 0.0290 m²/s²
Spectral Width Parameter ε = 0.6941
Peakedness Parameter Q_p = 2.9495
JONSWAP Peak Enhancement γ = 2.9068
Spectrum
Goodness of Fit
Observed
Scott 0.1157
P.M. 0.1427
JONSWAP 0.1172
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

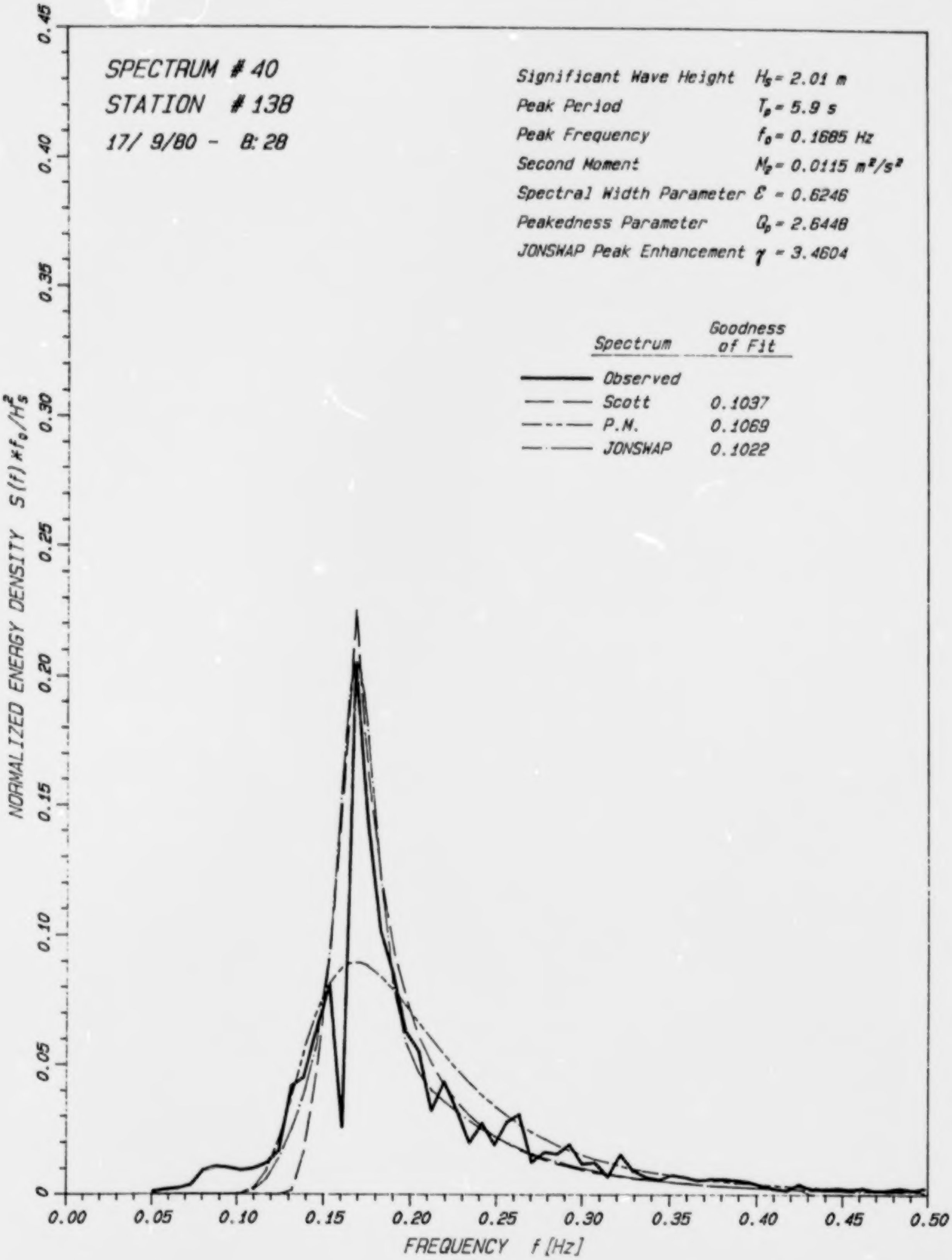

SPECTRUM # 37
STATION # 138
26/ 7/80 - 11: 00
Significant Wave Height H_s = 5.24 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0302 m^2/s^2
Spectral Width Parameter ε = 0.6833
Peakedness Parameter Q_p = 3.5607
JONSWAP Peak Enhancement γ = 2.9313
Spectrum
Goodness of Fit
Observed
Scott 0.1069
P.M. 0.1616
JONSWAP 0.0777
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

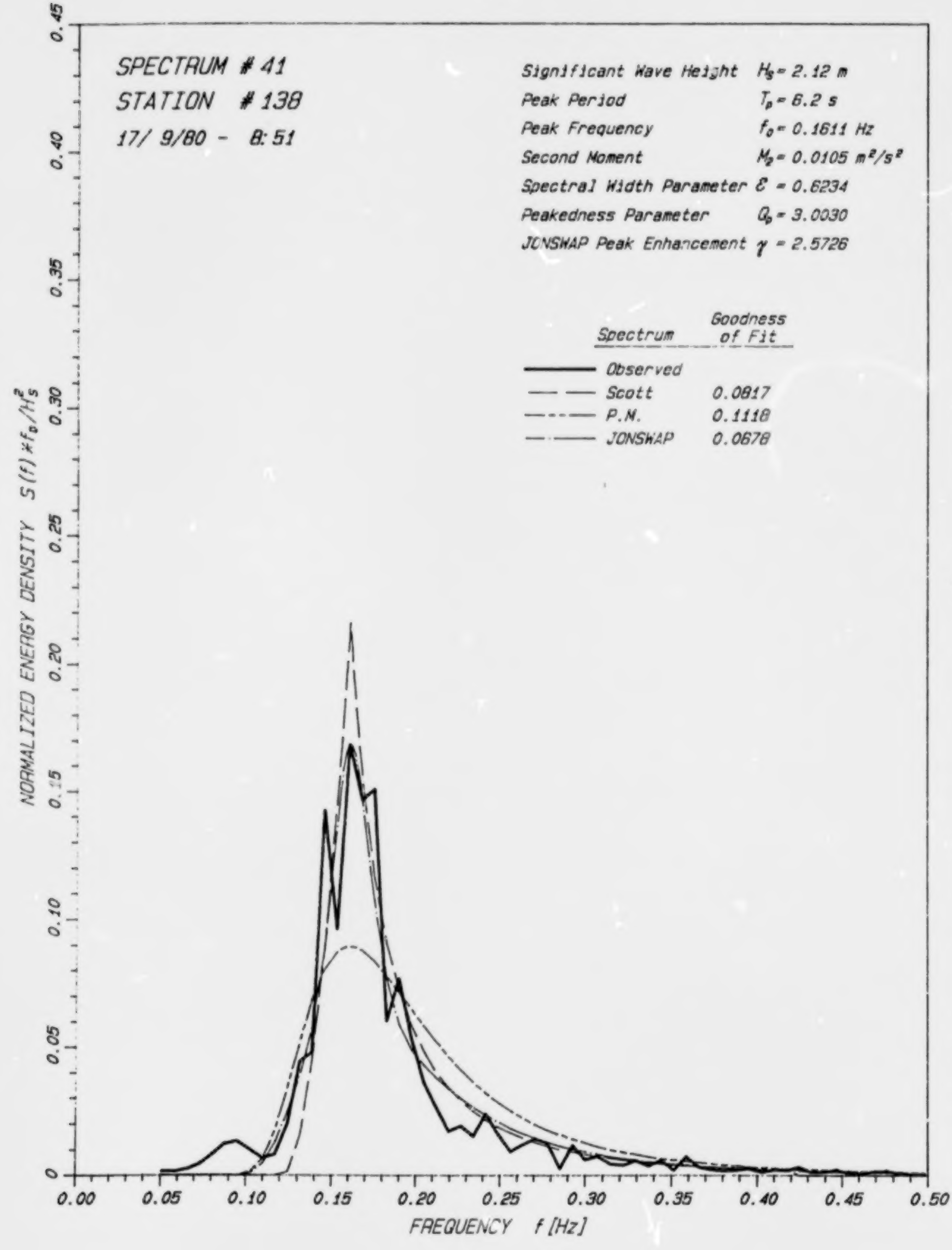

SPECTRUM # 38
STATION # 138
26/ 7/80 - 12:00
Significant Wave Height H_s = 5.35 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0318 m^2/s^2
Spectral Width Parameter ε = 0.7161
Peakedness Parameter Q_p = 3.5087
JONSWAP Peak Enhancement γ = 4.0020
Spectrum
Goodness of Fit
Observed
Scott 0.1258
P.M. 0.1781
JONSWAP 0.1018
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

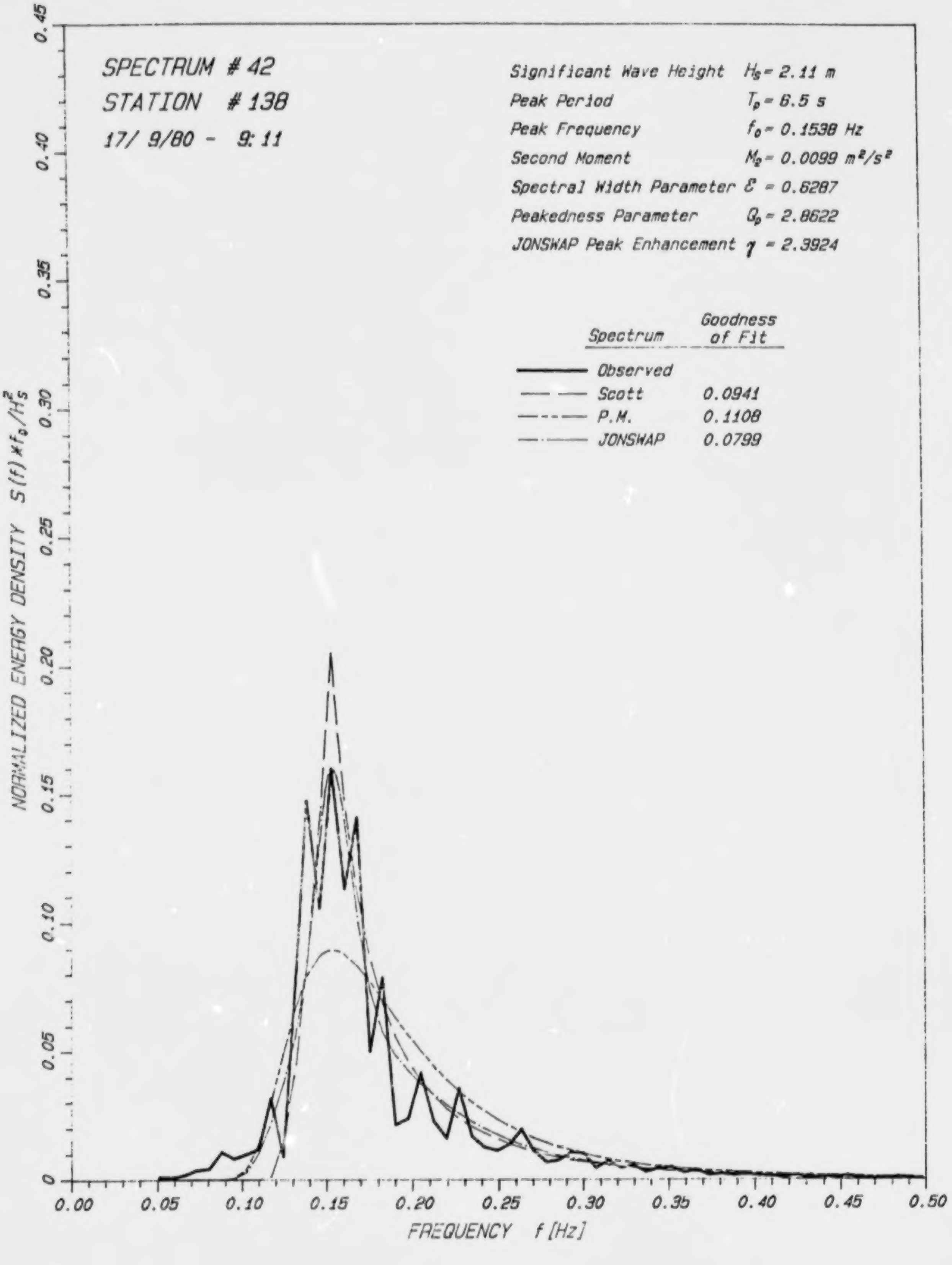


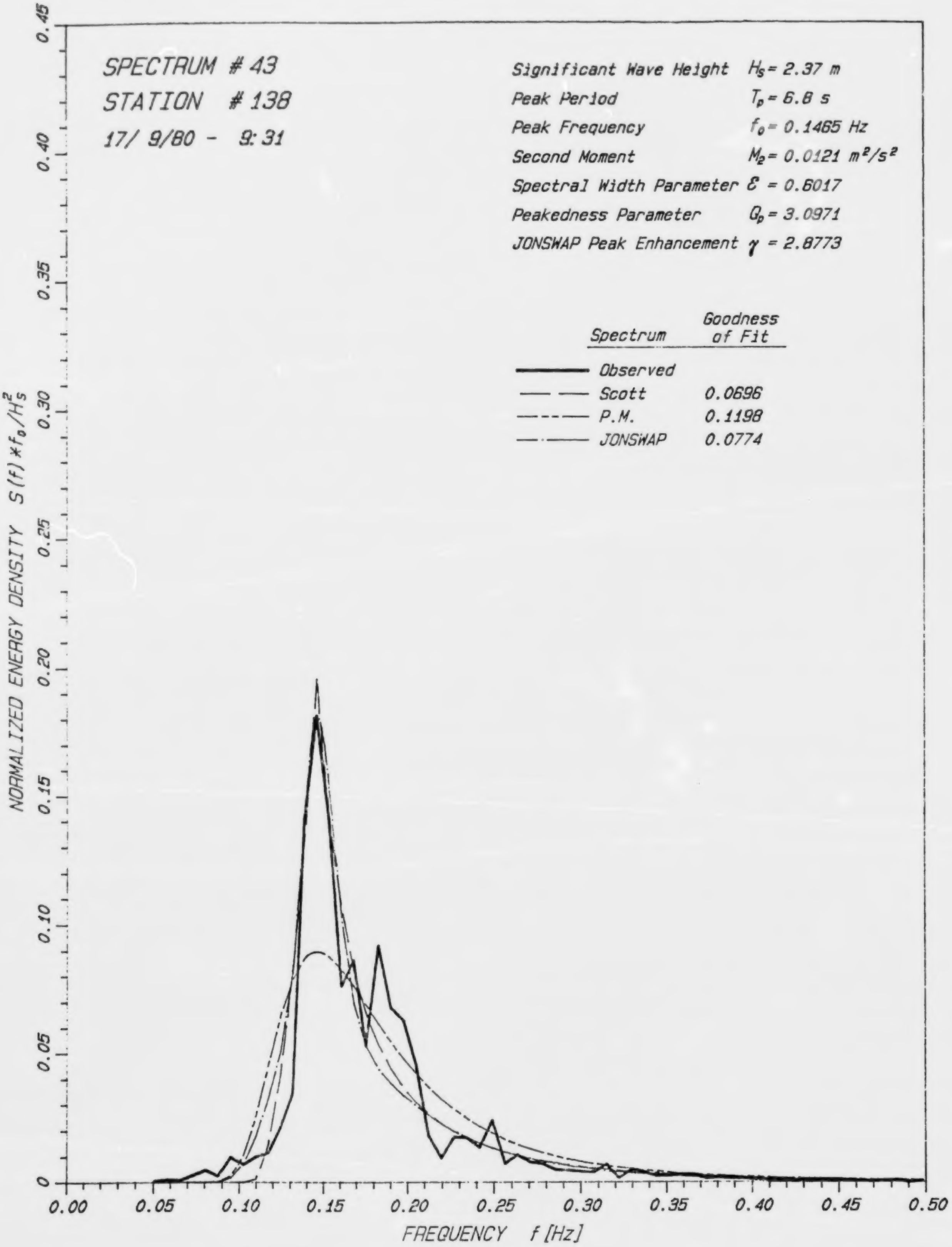
Significant Wave Height	H_s = 5.14 m
Peak Period	T_p = 10.5 s
Peak Frequency	f_0 = 0.0952 Hz
Second Moment	M_2 = 0.0289 m^2/s^2
Spectral Width Parameter	ε = 0.7138
Peakedness Parameter	Q_p = 3.2202
JONSWAP Peak Enhancement	γ = 2.8447

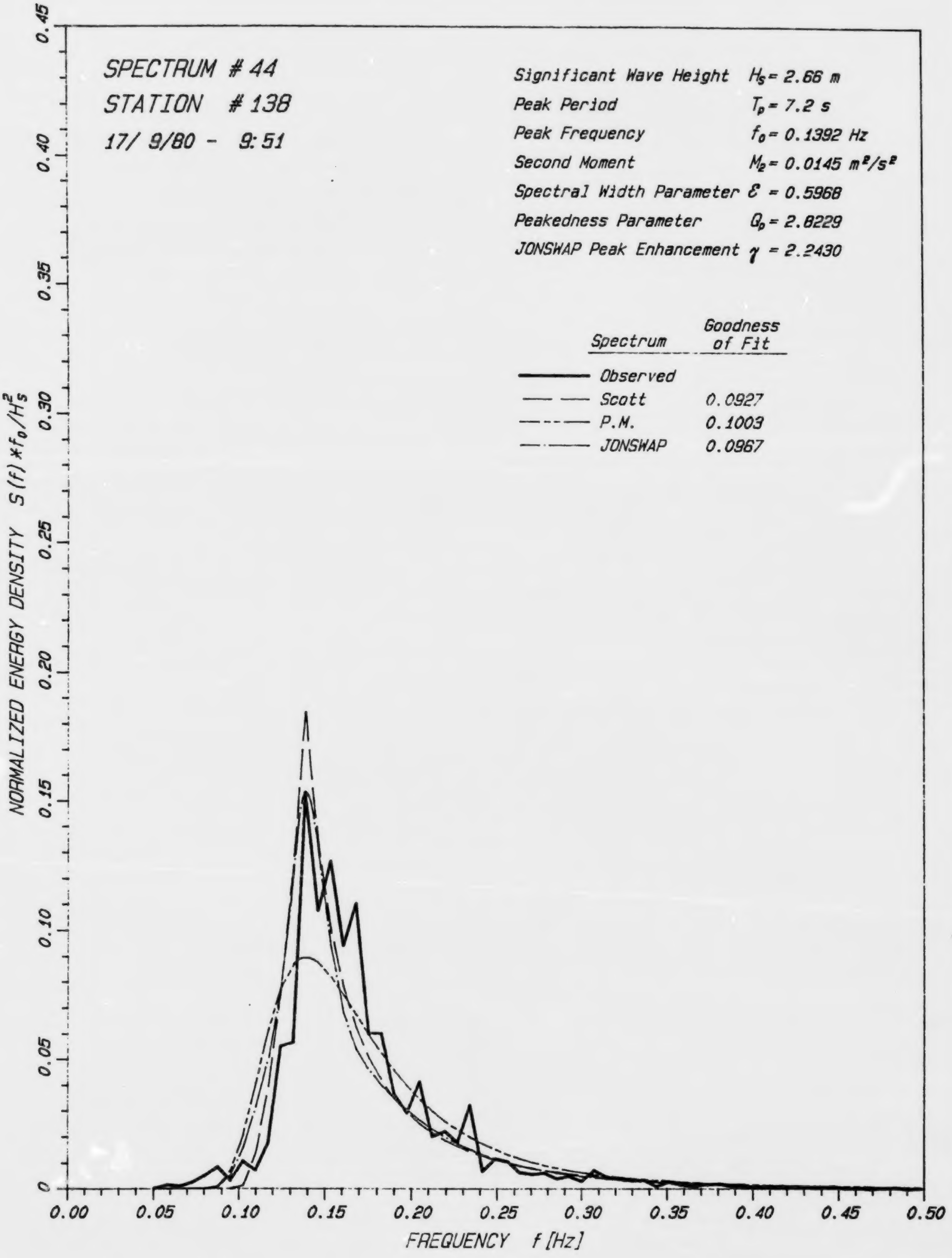
Spectrum	Goodness of Fit
Observed	
Scott	0.1407
P.M.	0.1691
JONSWAP	0.1360

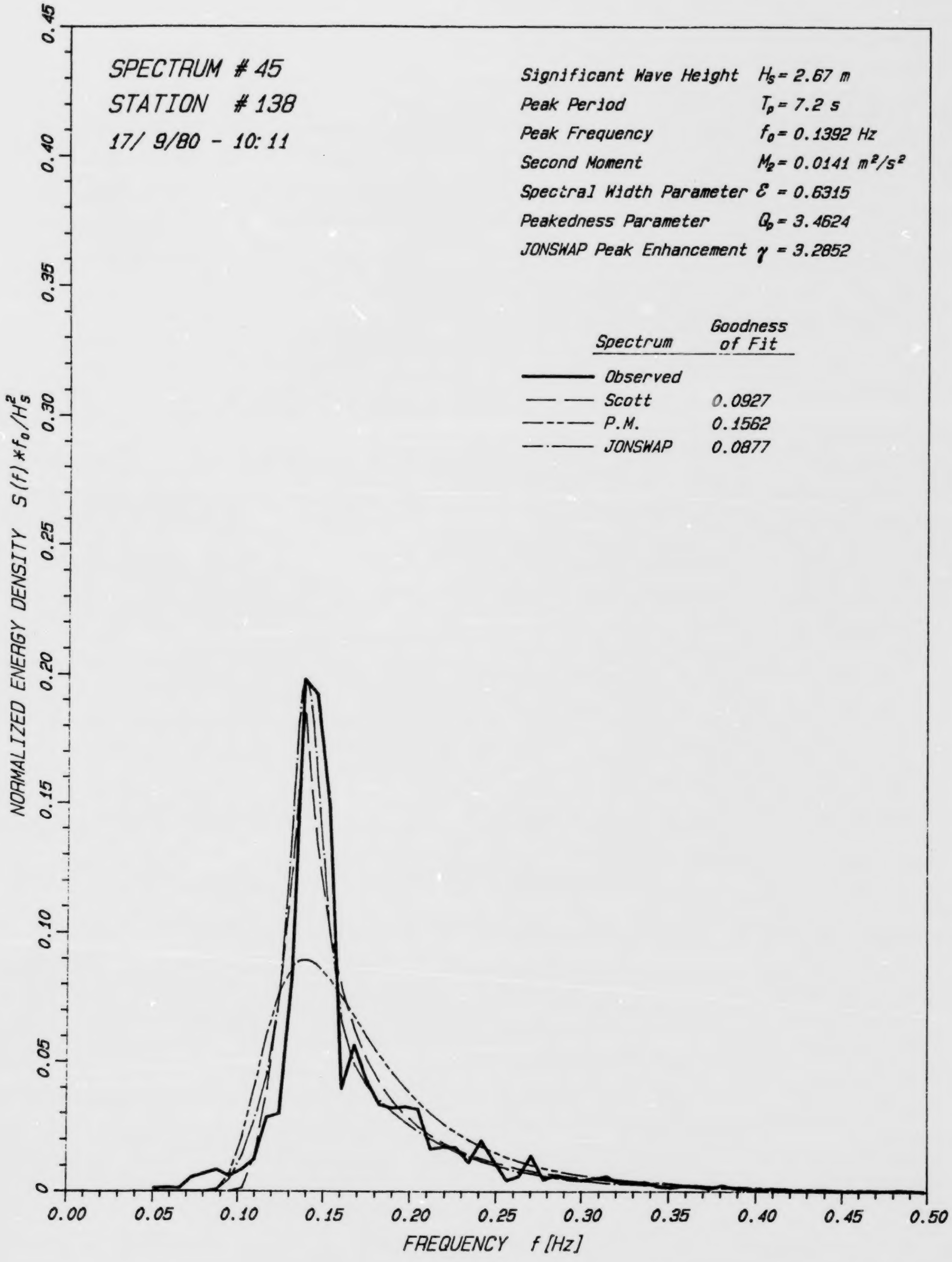

SPECTRUM # 40
STATION # 138
17/ 9/80 - 8:28
Significant Wave Height H_s = 2.01 m
Peak Period T_p = 5.9 s
Peak Frequency f_0 = 0.1685 Hz
Second Moment M_2 = 0.0115 m²/s²
Spectral Width Parameter ε = 0.6246
Peakedness Parameter Q_p = 2.6448
JONSWAP Peak Enhancement γ = 3.4604
Spectrum
Goodness of Fit
Observed
Scott 0.1037
P.M. 0.1069
JONSWAP 0.1022
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 41
STATION # 138
17/ 9/80 - 8:51
Significant Wave Height H_s = 2.12 m
Peak Period T_p = 6.2 s
Peak Frequency f_0 = 0.1611 Hz
Second Moment M_2 = 0.0105 m^2/s^2
Spectral Width Parameter ε = 0.6234
Peakedness Parameter Q_p = 3.0030
JONSWAP Peak Enhancement γ = 2.5726
Spectrum
Goodness of Fit
Observed
Scott 0.0817
P.M. 0.1118
JONSWAP 0.0678
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 42
STATION # 138
17/ 9/80 - 9: 11
Significant Wave Height H_s = 2.11 m
Peak Period T_p = 6.5 s
Peak Frequency f_0 = 0.1538 Hz
Second Moment M_2 = 0.0099 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6287
Peakedness Parameter Q_p = 2.8622
JONSWAP Peak Enhancement γ = 2.3924
Spectrum
Goodness of Fit
Observed
Scott 0.0941
P.M. 0.1108
JONSWAP 0.0799
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 43
STATION # 138
17/ 9/80 - 9: 31
Significant Wave Height H_s = 2.37 m
Peak Period T_p = 6.8 s
Peak Frequency f_0 = 0.1465 Hz
Second Moment M_2 = 0.0121 m^2/s^2
Spectral Width Parameter ε = 0.6017
Peakedness Parameter Q_p = 3.0971
JONSWAP Peak Enhancement γ = 2.8773
Spectrum
Goodness of Fit
Observed
Scott 0.0696
P.M. 0.1198
JONSWAP 0.0774
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

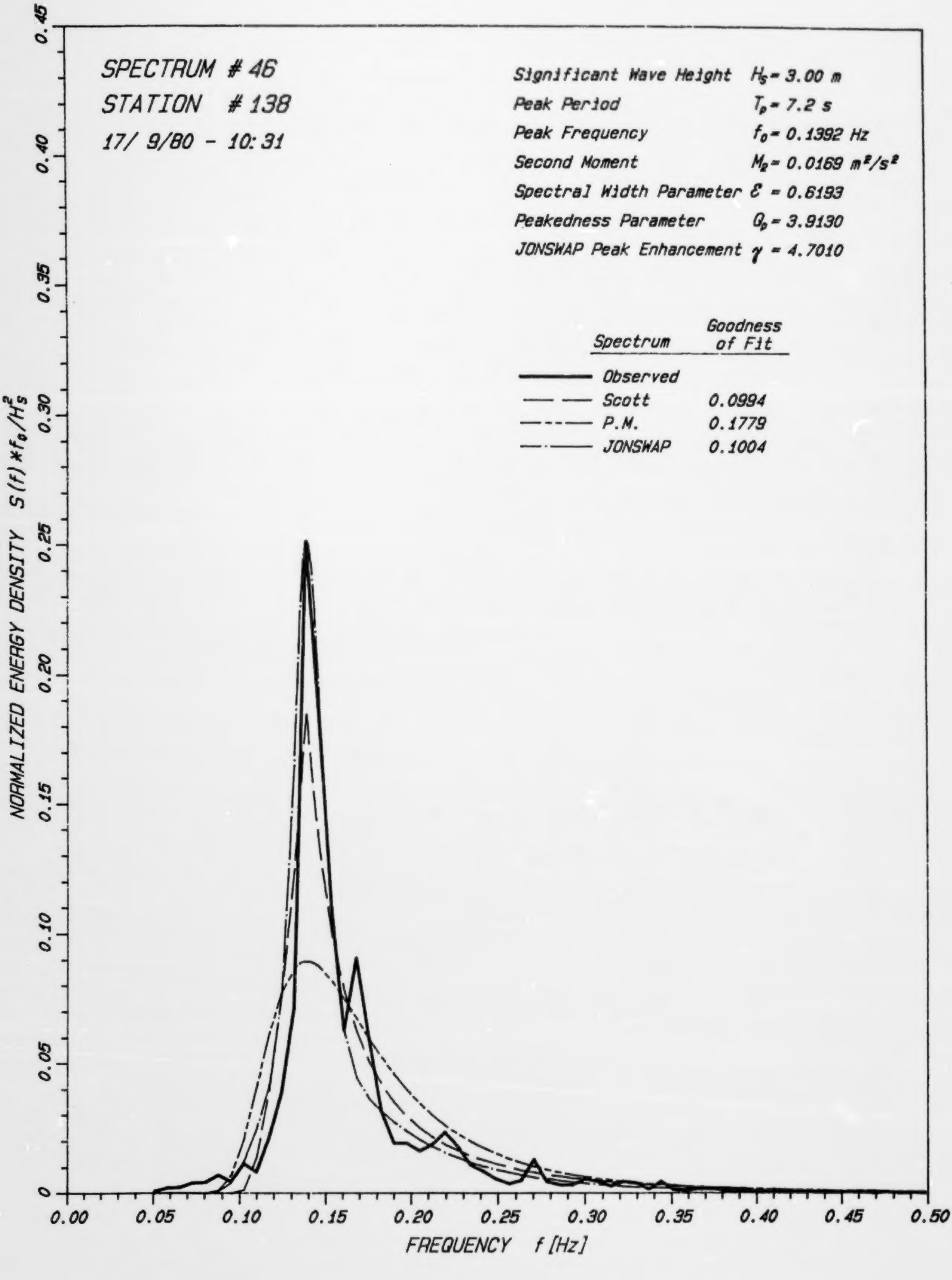

SPECTRUM # 44
STATION # 138
17/ 9/80 - 9:51
Significant Wave Height H_s= 2.66 m
Peak Period T_p= 7.2 s
Peak Frequency f_0= 0.1392 Hz
Second Moment M_2= 0.0145 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.5968
Peakedness Parameter Q_p= 2.8229
JONSWAP Peak Enhancement γ = 2.2430
Spectrum
Goodness of Fit
Observed
Scott 0.0927
P.M. 0.1003
JONSWAP 0.0967
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

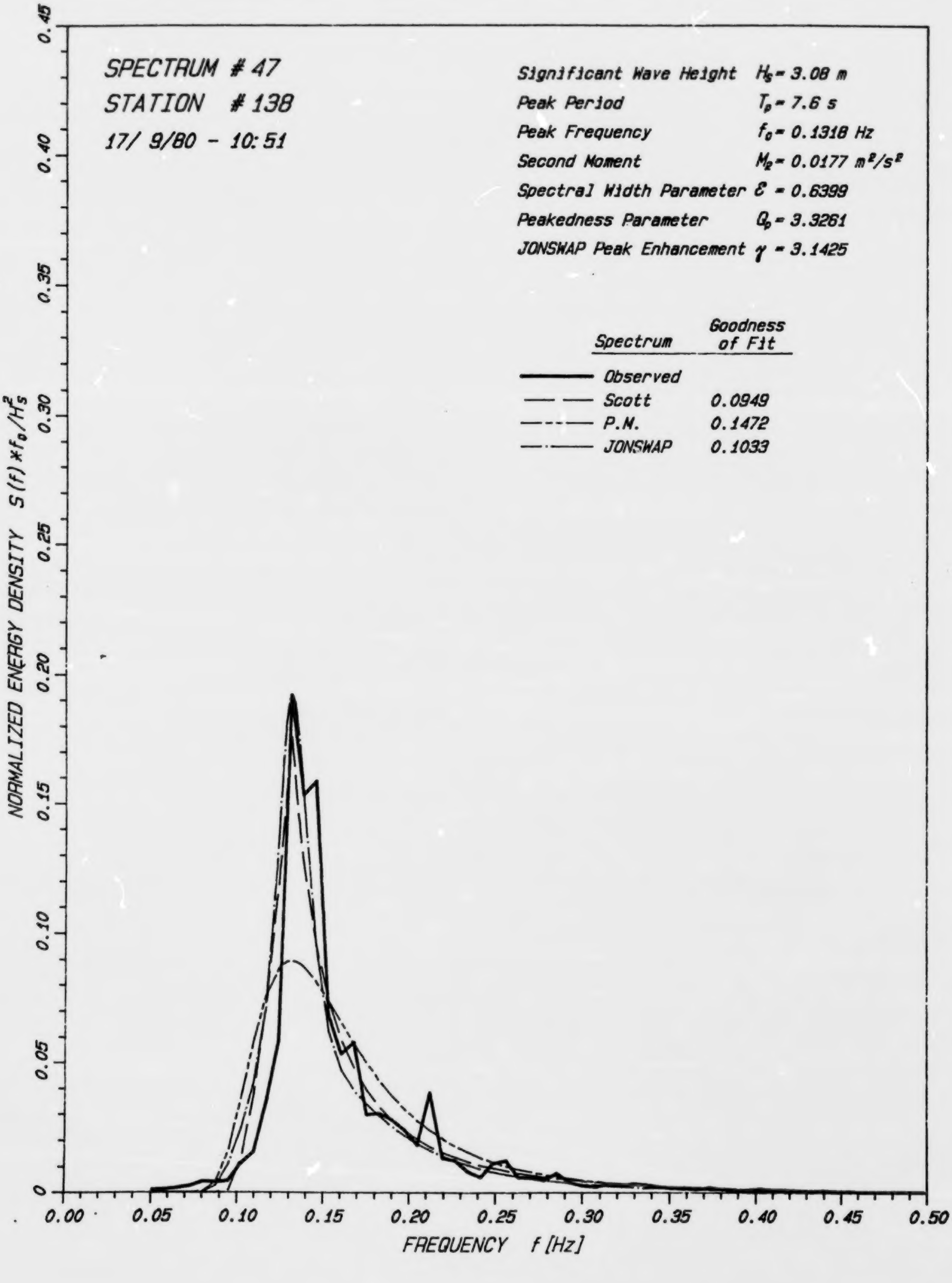


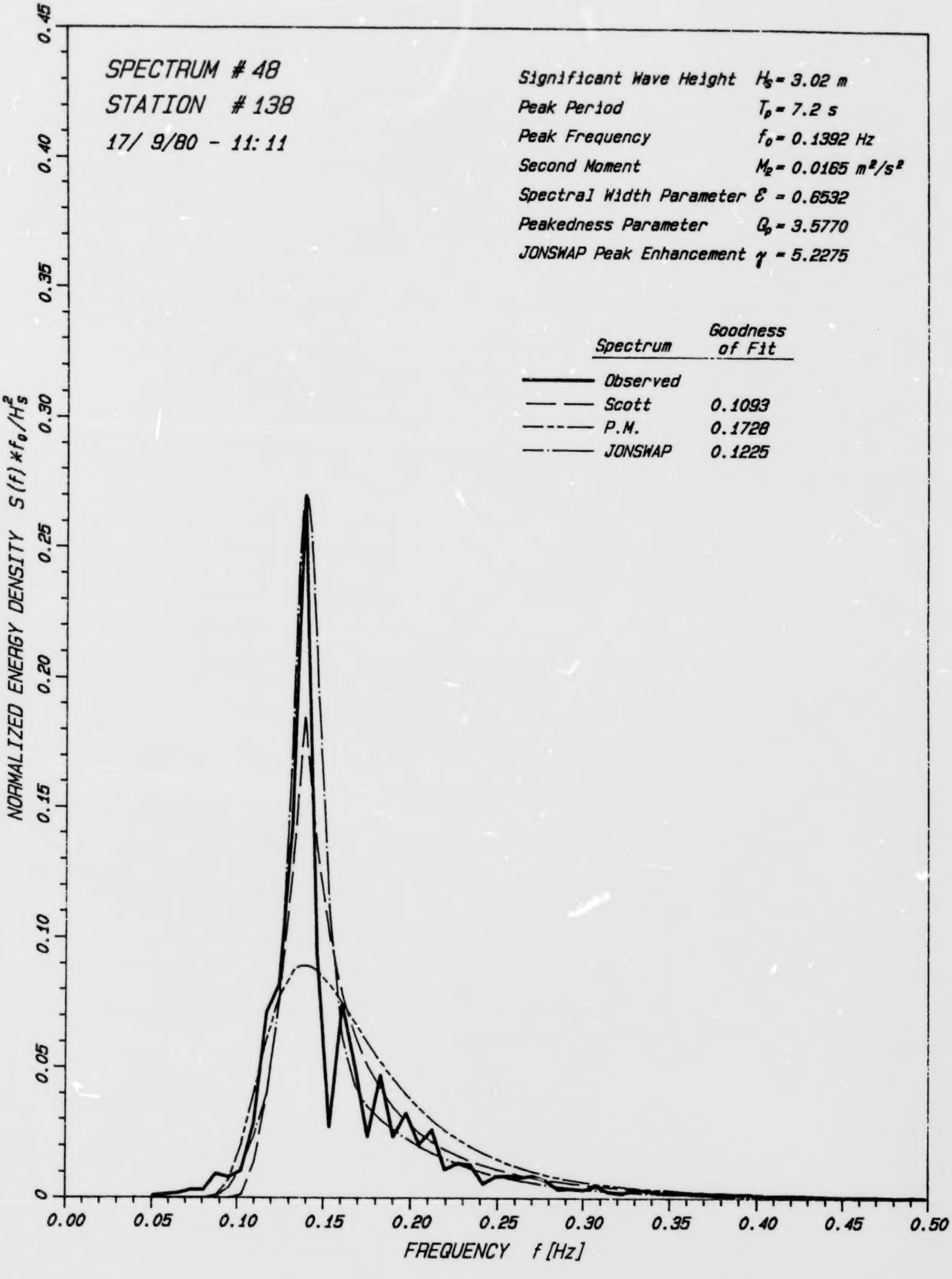
SPECTRUM # 45
STATION # 138
17/ 9/80 - 10: 11

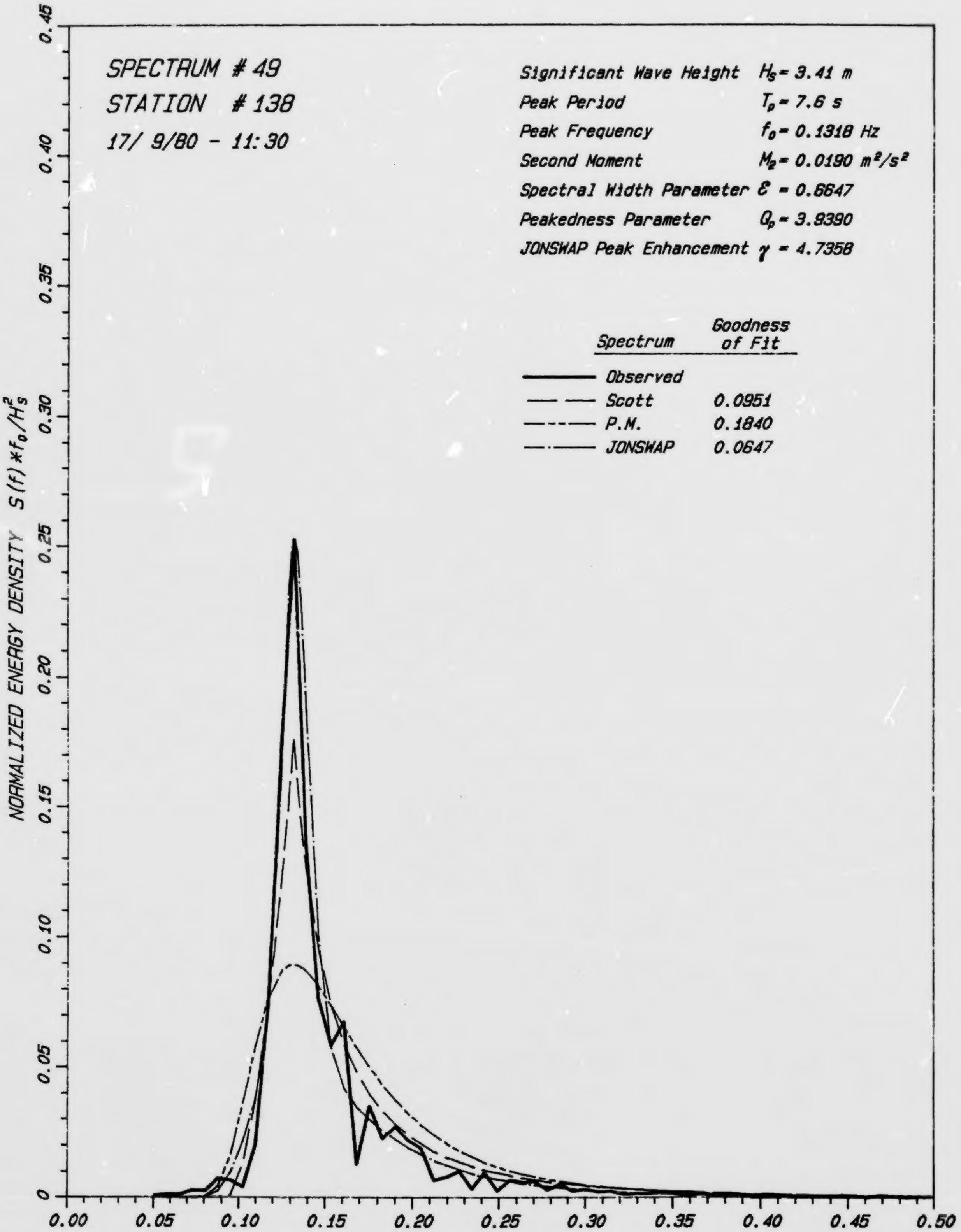
Significant Wave Height $H_s = 2.67$ m
Peak Period $T_p = 7.2$ s
Peak Frequency $f_0 = 0.1392$ Hz
Second Moment $M_2 = 0.0141\ m^2/s^2$
Spectral Width Parameter $\mathcal{E} = 0.6315$
Peakedness Parameter $Q_p = 3.4624$
JONSWAP Peak Enhancement $\gamma = 3.2852$

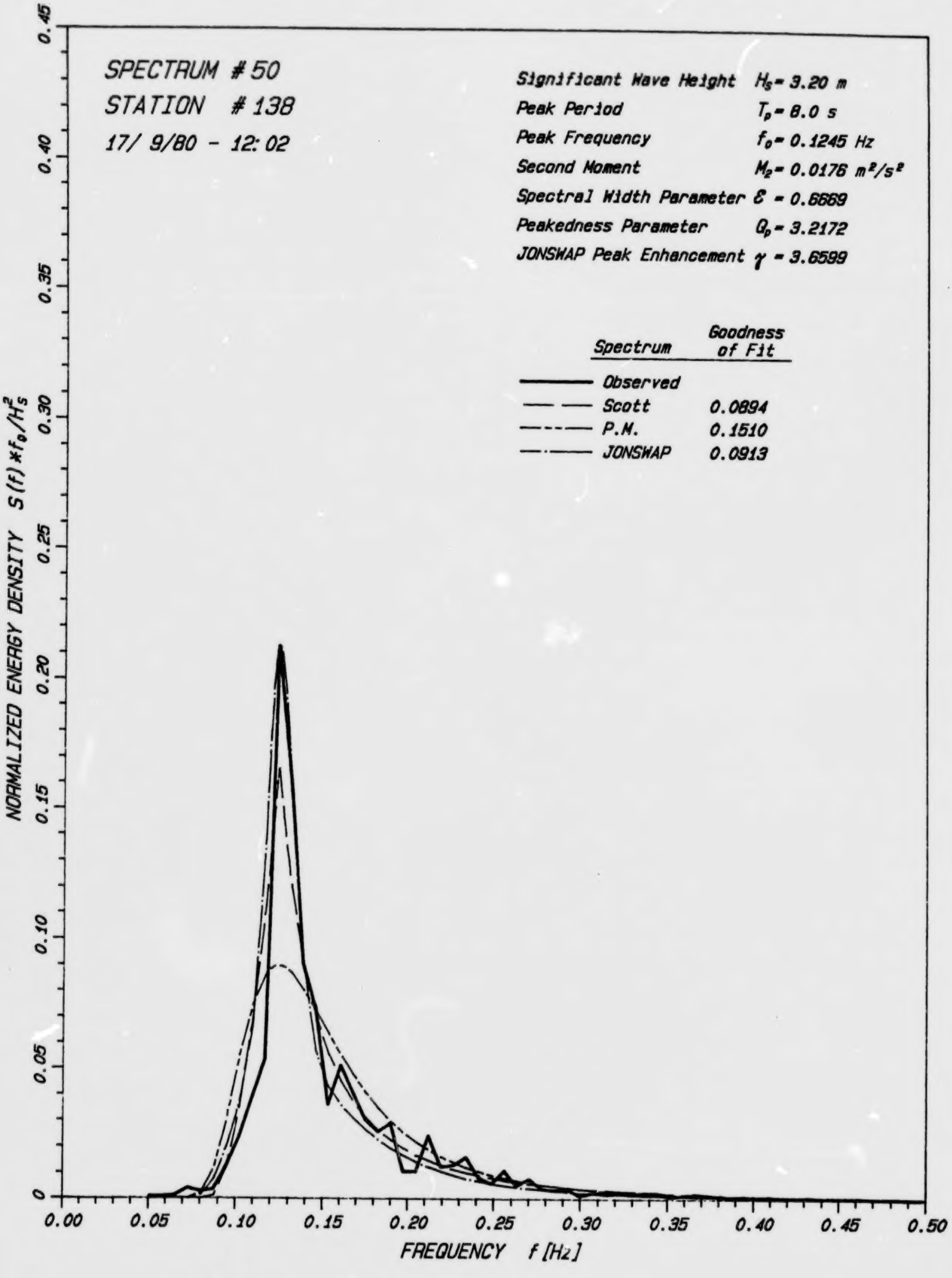
Spectrum	Goodness of Fit
Observed	
Scott	0.0927
P.M.	0.1562
JONSWAP	0.0877

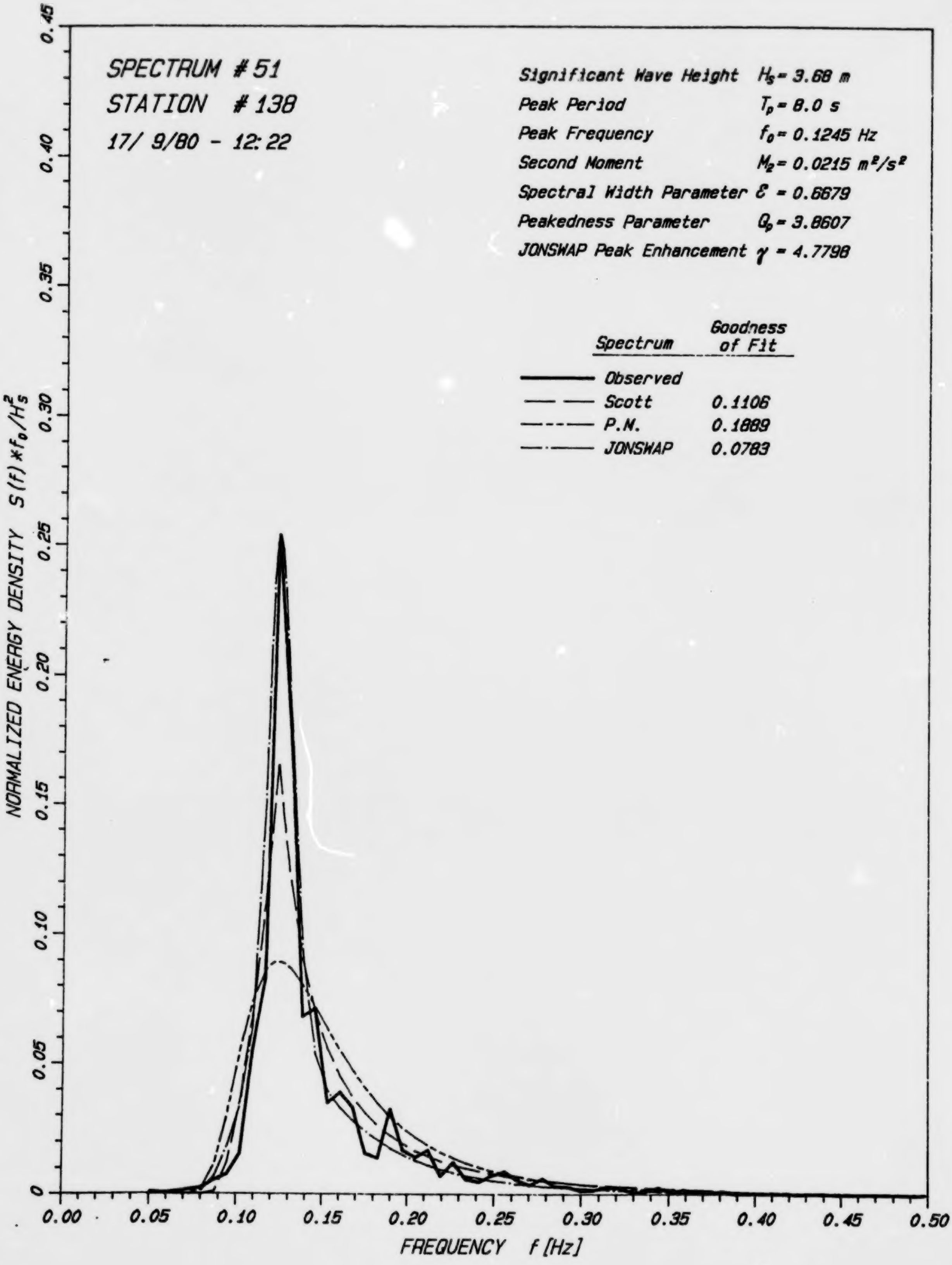

SPECTRUM # 46
STATION # 138
17/ 9/80 - 10:31
Significant Wave Height H_s = 3.00 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0169 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6193
Peakedness Parameter Q_p = 3.9130
JONSWAP Peak Enhancement γ = 4.7010
Spectrum
Goodness of Fit
Observed
Scott 0.0994
P.M. 0.1779
JONSWAP 0.1004
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

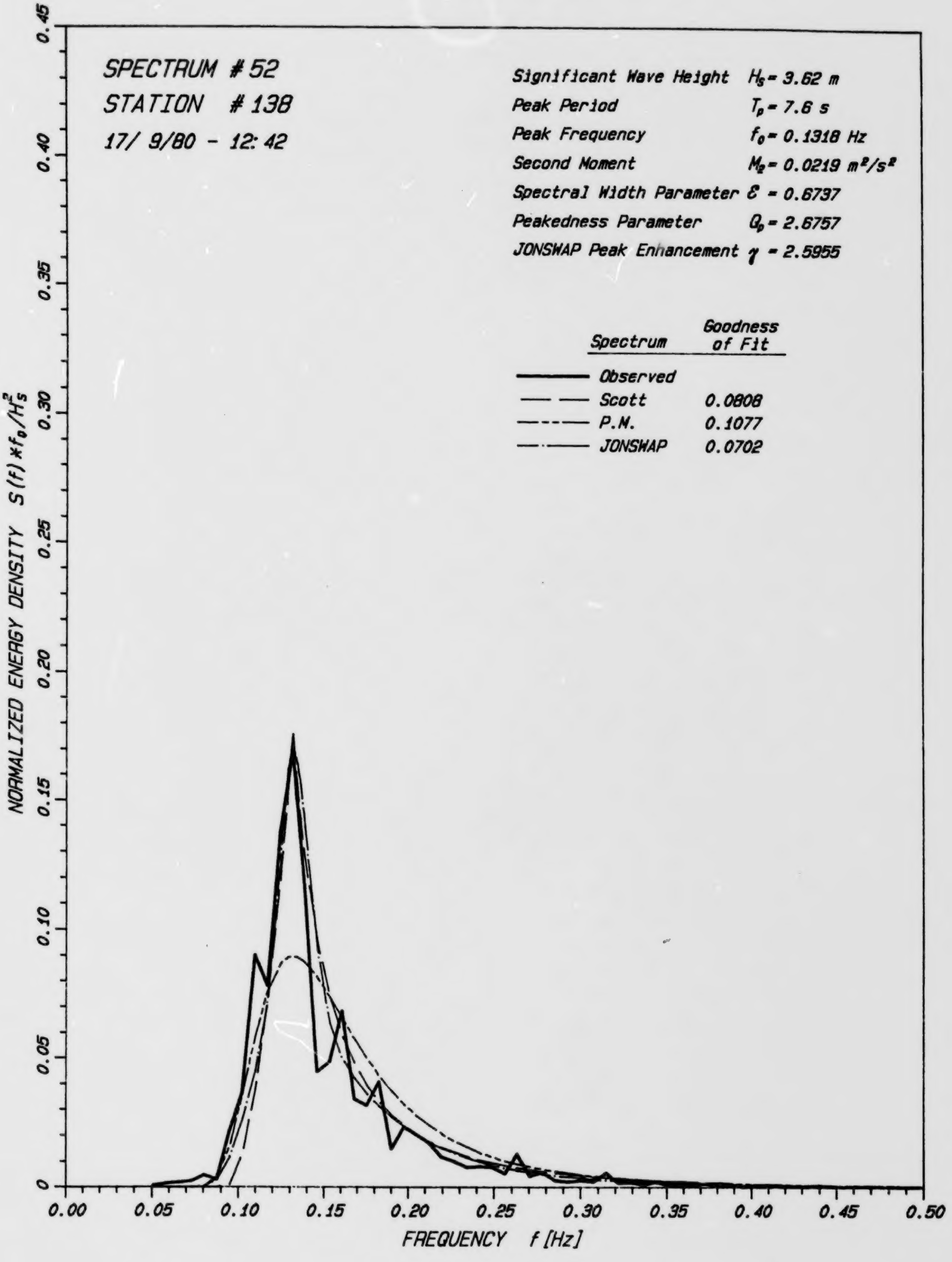

SPECTRUM # 47
STATION # 138
17/ 9/80 - 10:51
Significant Wave Height H_s = 3.08 m
Peak Period T_p = 7.6 s
Peak Frequency f_0 = 0.1318 Hz
Second Moment M_2 = 0.0177 m²/s²
Spectral Width Parameter ε = 0.6399
Peakedness Parameter Q_p = 3.3261
JONSWAP Peak Enhancement γ = 3.1425
Spectrum
Goodness of Fit
Observed
Scott 0.0949
P.M. 0.1472
JONSWAP 0.1033
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

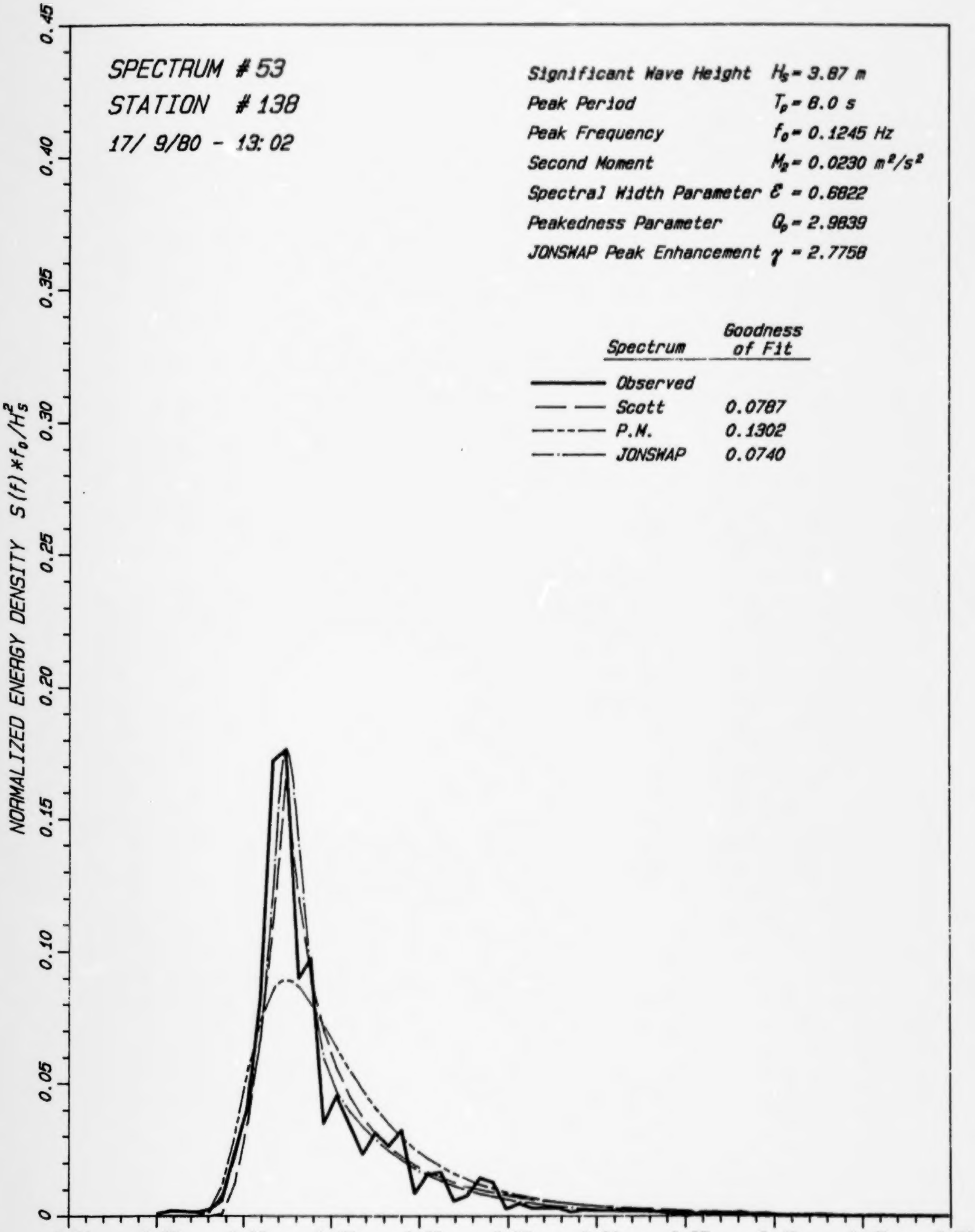

SPECTRUM # 48
STATION # 138
17/ 9/80 - 11:11
Significant Wave Height H_s = 3.02 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0165 m²/s²
Spectral Width Parameter ε = 0.6532
Peakedness Parameter Q_p = 3.5770
JONSWAP Peak Enhancement γ = 5.2275
Spectrum
Goodness of Fit
Observed
Scott 0.1093
P.M. 0.1728
JONSWAP 0.1225
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

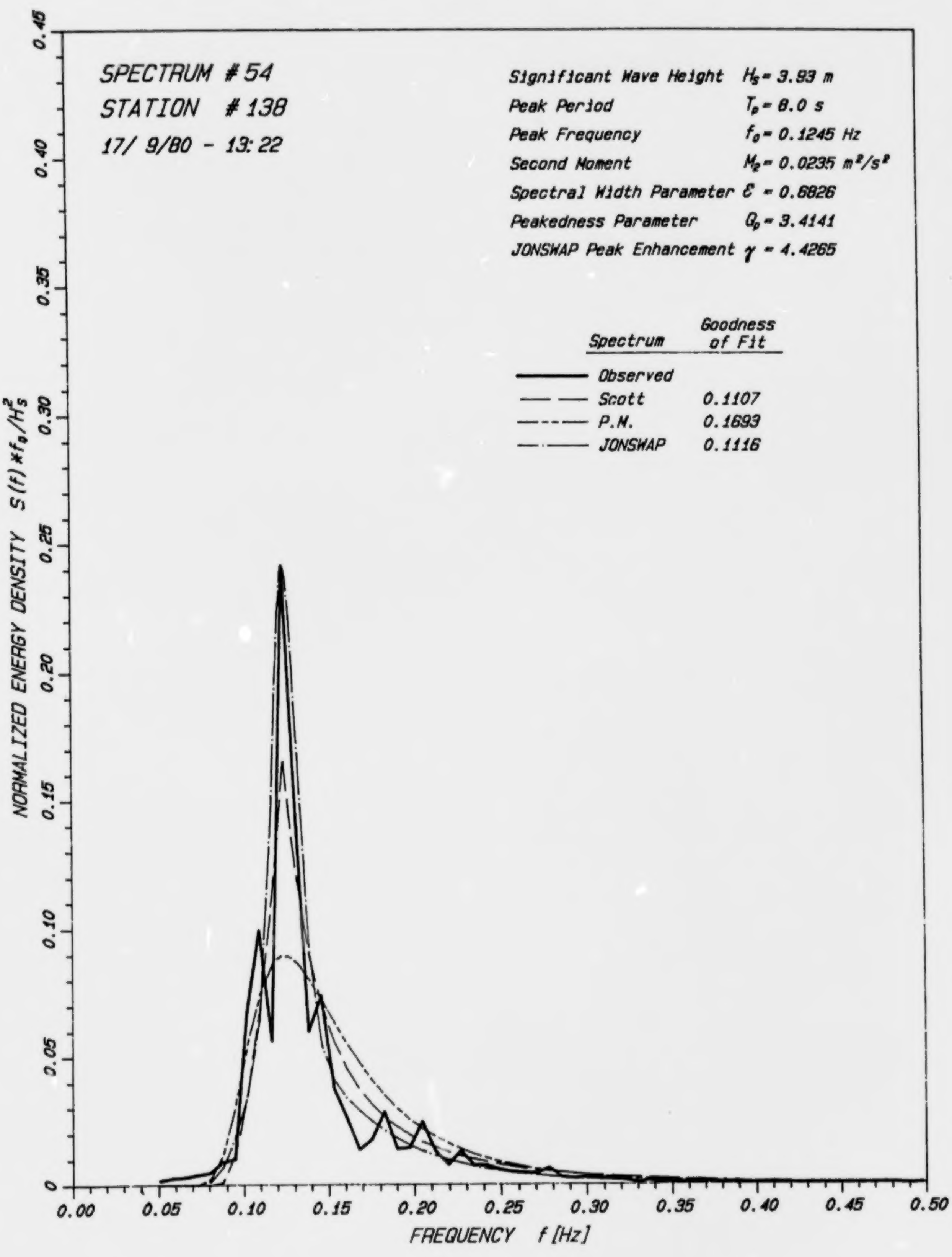

SPECTRUM # 49
STATION # 138
17/ 9/80 - 11:30
Significant Wave Height H_s = 3.41 m
Peak Period T_p = 7.6 s
Peak Frequency f_0 = 0.1318 Hz
Second Moment M_2 = 0.0190 m²/s²
Spectral Width Parameter ε = 0.6647
Peakedness Parameter Q_p = 3.9390
JONSWAP Peak Enhancement γ = 4.7358
Spectrum
Goodness of Fit
Observed
Scott 0.0951
P.M. 0.1840
JONSWAP 0.0647
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

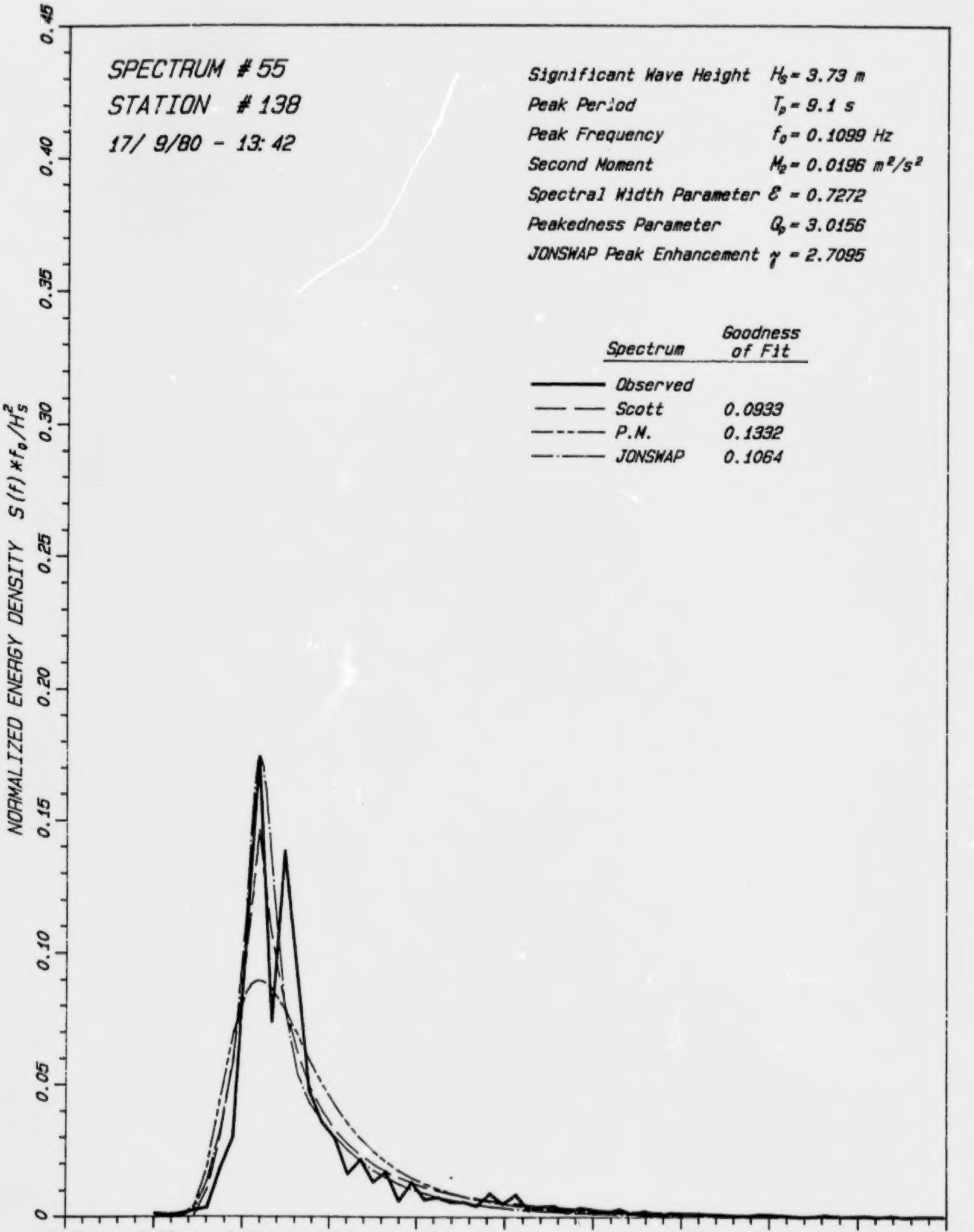

SPECTRUM # 50
STATION # 138
17/ 9/80 - 12: 02
Significant Wave Height H_s = 3.20 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0176 m^2/s^2
Spectral Width Parameter ε = 0.6669
Peakedness Parameter Q_p = 3.2172
JONSWAP Peak Enhancement γ = 3.6599
Spectrum
Goodness of Fit
Observed
Scott 0.0894
P.M. 0.1510
JONSWAP 0.0913
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

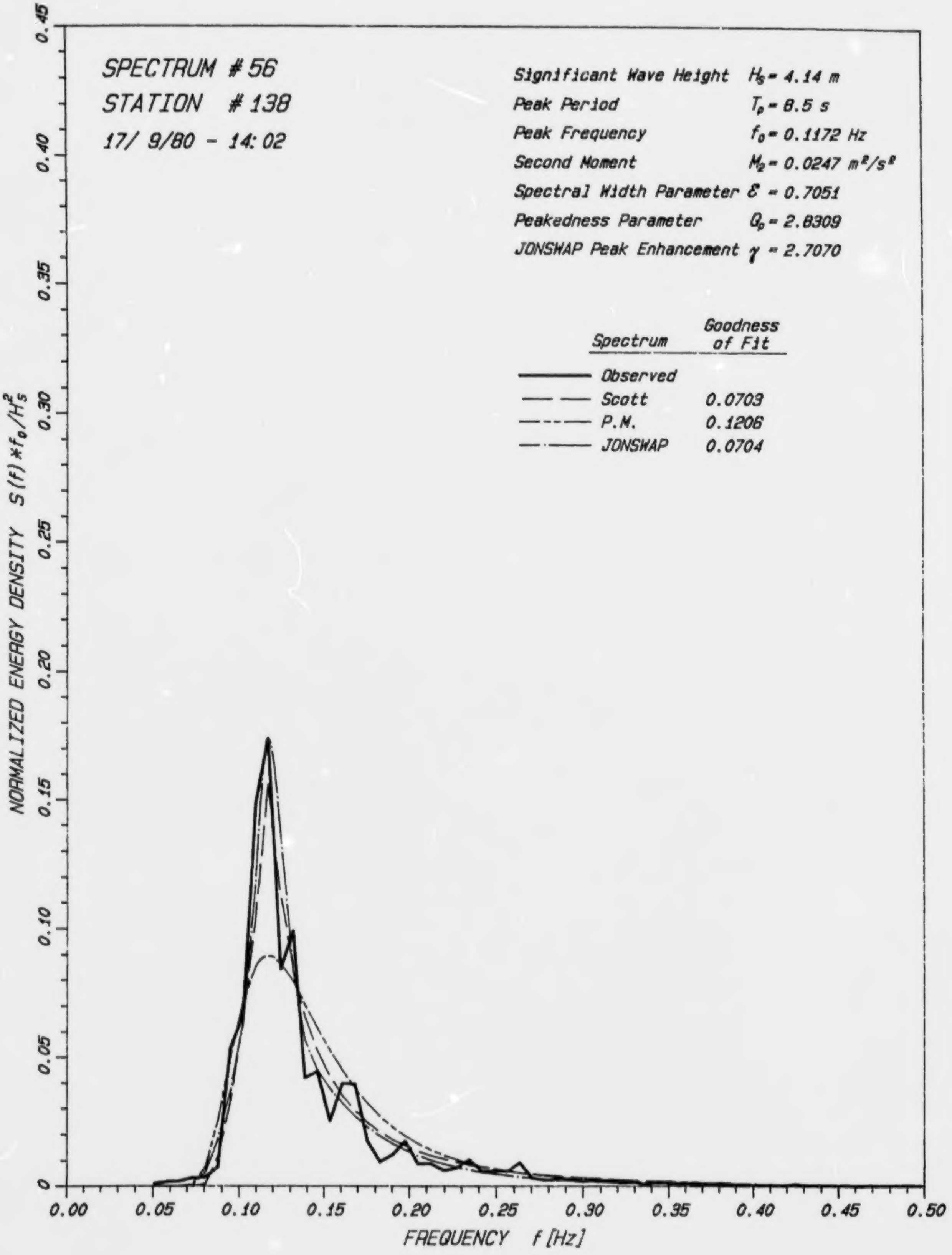

SPECTRUM # 51
STATION # 138
17/ 9/80 - 12:22
Significant Wave Height H_s = 3.68 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0215 m^2/s^2
Spectral Width Parameter ε = 0.6679
Peakedness Parameter Q_p = 3.8607
JONSWAP Peak Enhancement γ = 4.7798
Spectrum
Goodness of Fit
Observed
Scott 0.1106
P.M. 0.1889
JONSWAP 0.0783
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

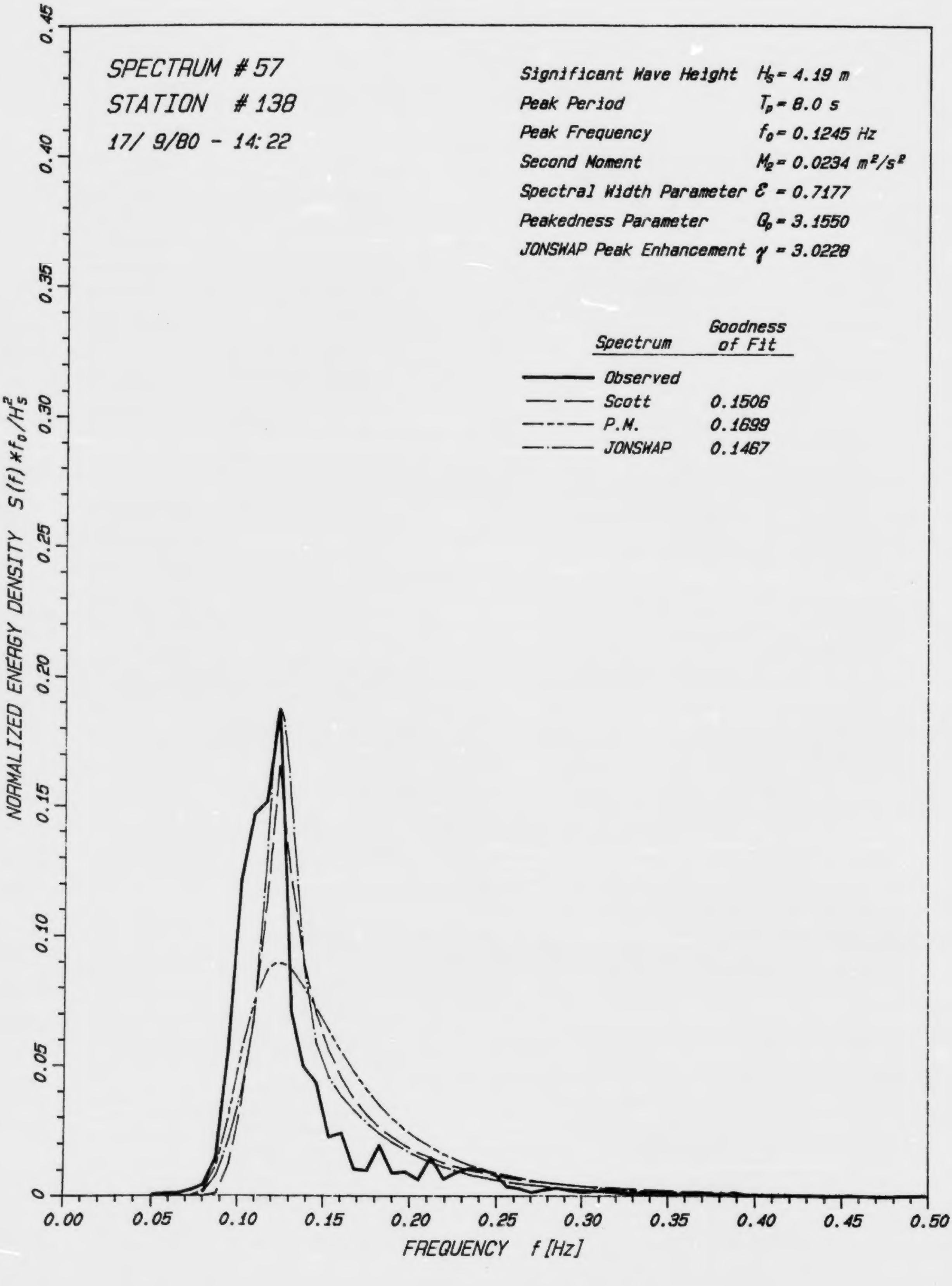

SPECTRUM # 52
STATION # 138
17/ 9/80 - 12: 42
Significant Wave Height H_s = 3.62 m
Peak Period T_p = 7.6 s
Peak Frequency f_0 = 0.1318 Hz
Second Moment M_2 = 0.0219 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6737
Peakedness Parameter Q_p = 2.6757
JONSWAP Peak Enhancement γ = 2.5955
Spectrum
Goodness of Fit
Observed
Scott 0.0808
P.M. 0.1077
JONSWAP 0.0702
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

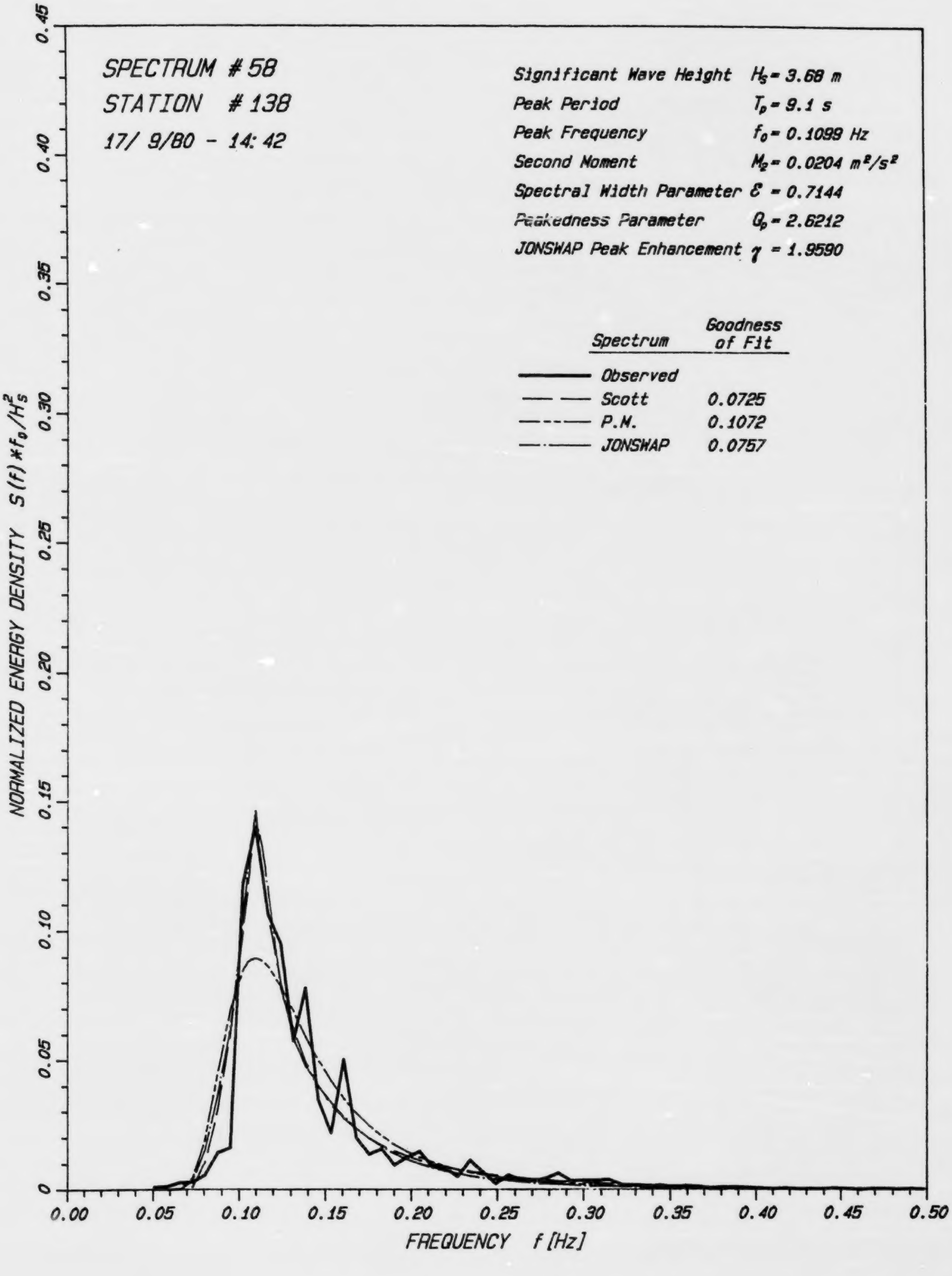

SPECTRUM # 53
STATION # 138
17/ 9/80 - 13: 02
Significant Wave Height H_s = 3.87 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0230 m²/s²
Spectral Width Parameter ε = 0.6822
Peakedness Parameter Q_p = 2.9839
JONSWAP Peak Enhancement γ = 2.7758
Spectrum
Goodness of Fit
Observed
Scott 0.0787
P.M. 0.1302
JONSWAP 0.0740
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

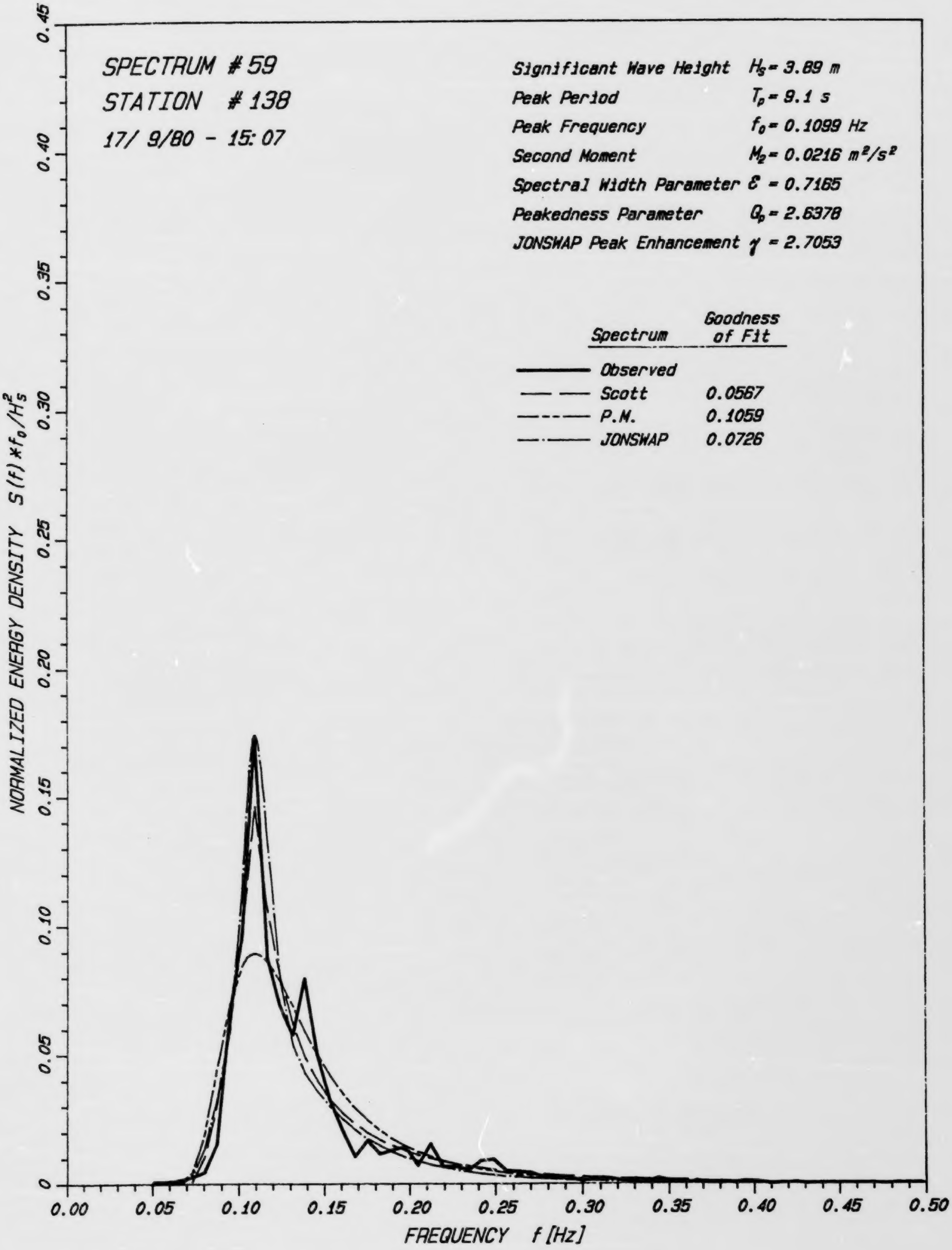

SPECTRUM # 54
STATION # 138
17/ 9/80 - 13:22
Significant Wave Height H_s = 3.93 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0235 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6826
Peakedness Parameter Q_p = 3.4141
JONSWAP Peak Enhancement γ = 4.4265
Spectrum
Goodness of Fit
Observed
Scott 0.1107
P.M. 0.1693
JONSWAP 0.1116
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

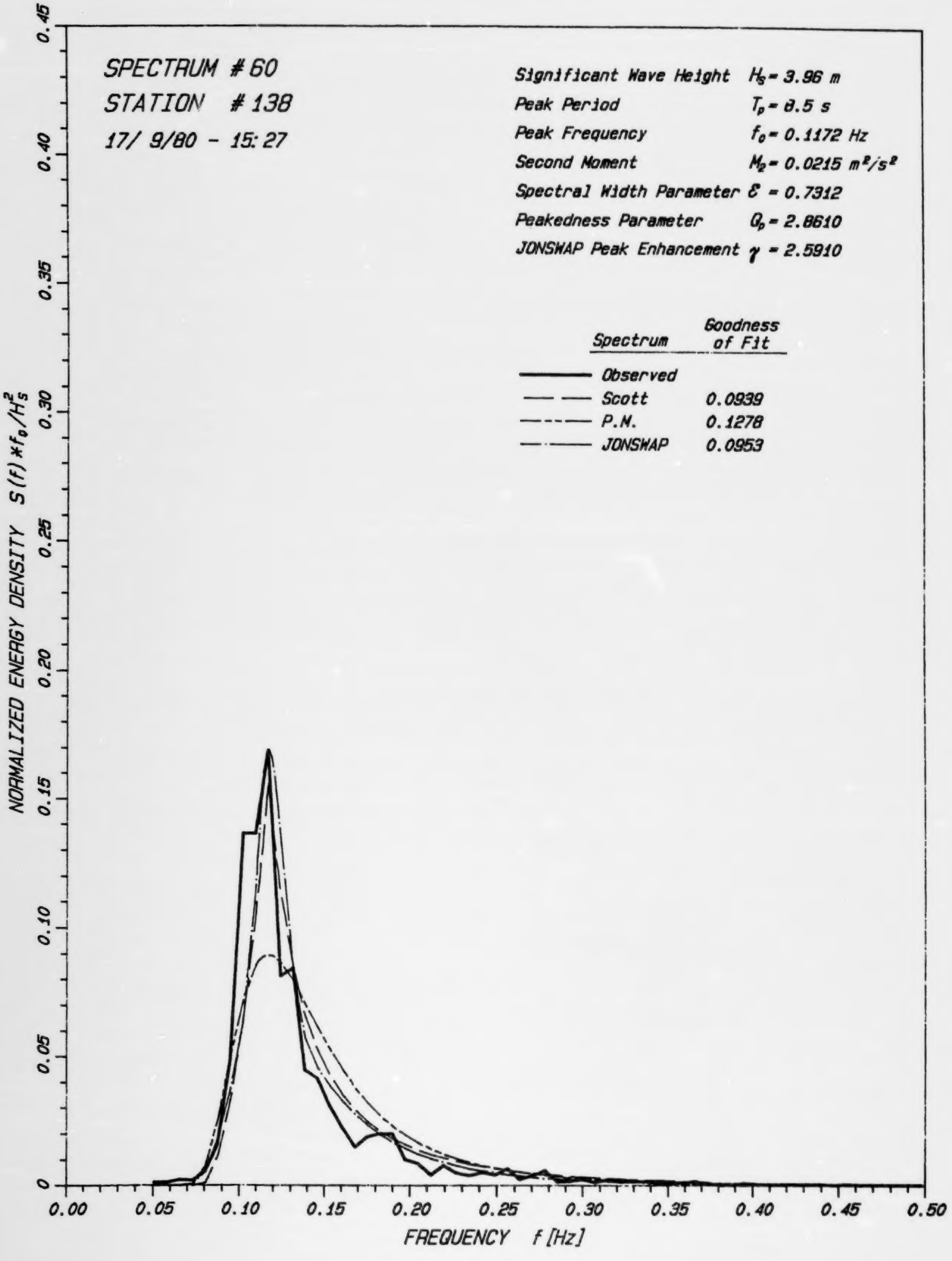

SPECTRUM # 55
STATION # 138
17/ 9/80 - 13: 42
Significant Wave Height H_s = 3.73 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0196 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.7272
Peakedness Parameter Q_p = 3.0156
JONSWAP Peak Enhancement γ = 2.7095
Spectrum
Goodness of Fit
Observed
Scott 0.0933
P.M. 0.1332
JONSWAP 0.1064
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

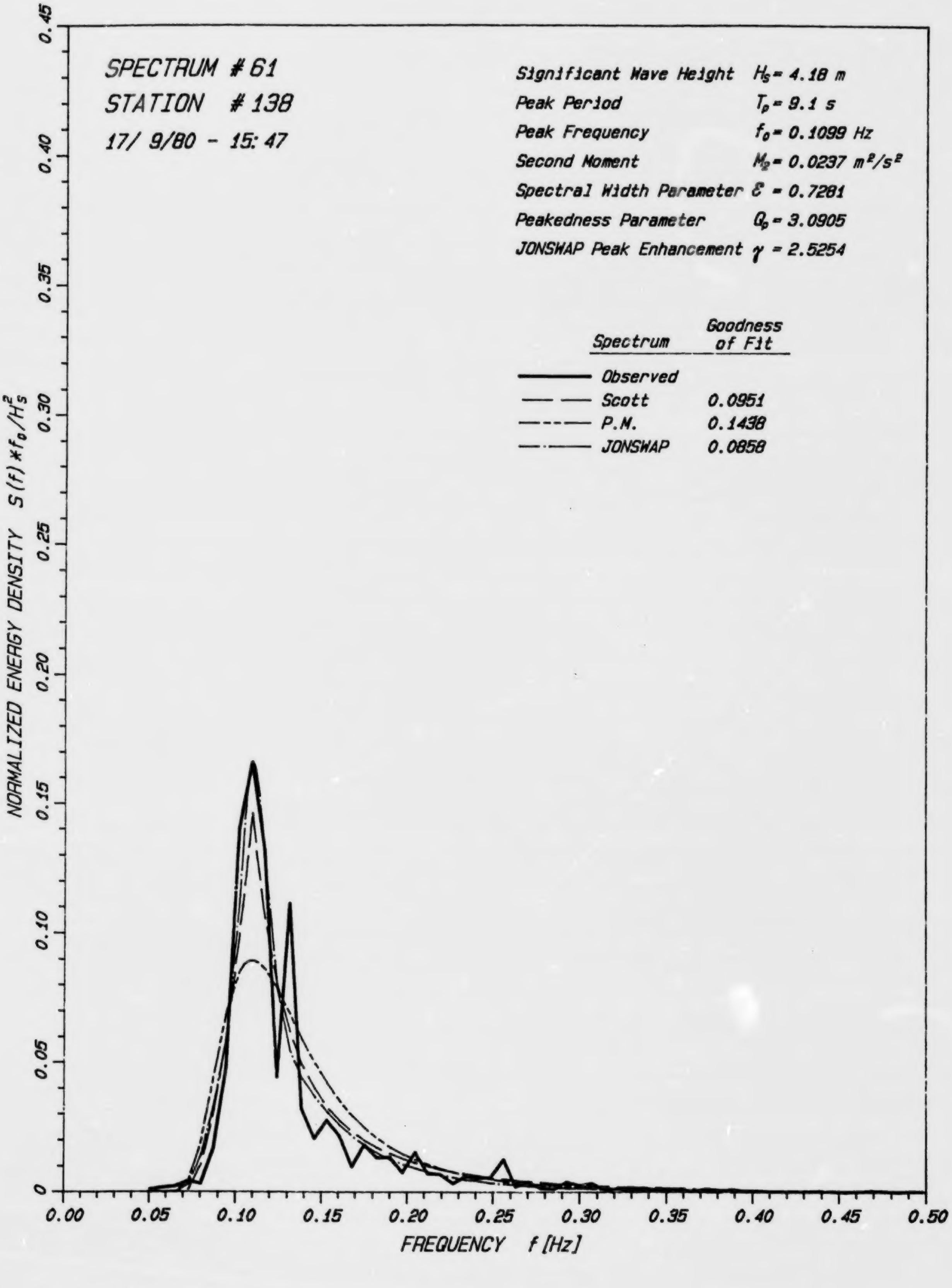

SPECTRUM # 56
STATION # 138
17/ 9/80 - 14: 02
Significant Wave Height H_s = 4.14 m
Peak Period T_p = 8.5 s
Peak Frequency f_0 = 0.1172 Hz
Second Moment M_2 = 0.0247 m²/s²
Spectral Width Parameter ε = 0.7051
Peakedness Parameter Q_p = 2.8309
JONSWAP Peak Enhancement γ = 2.7070
Spectrum
Goodness of Fit
Observed
Scott 0.0703
P.M. 0.1206
JONSWAP 0.0704
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]

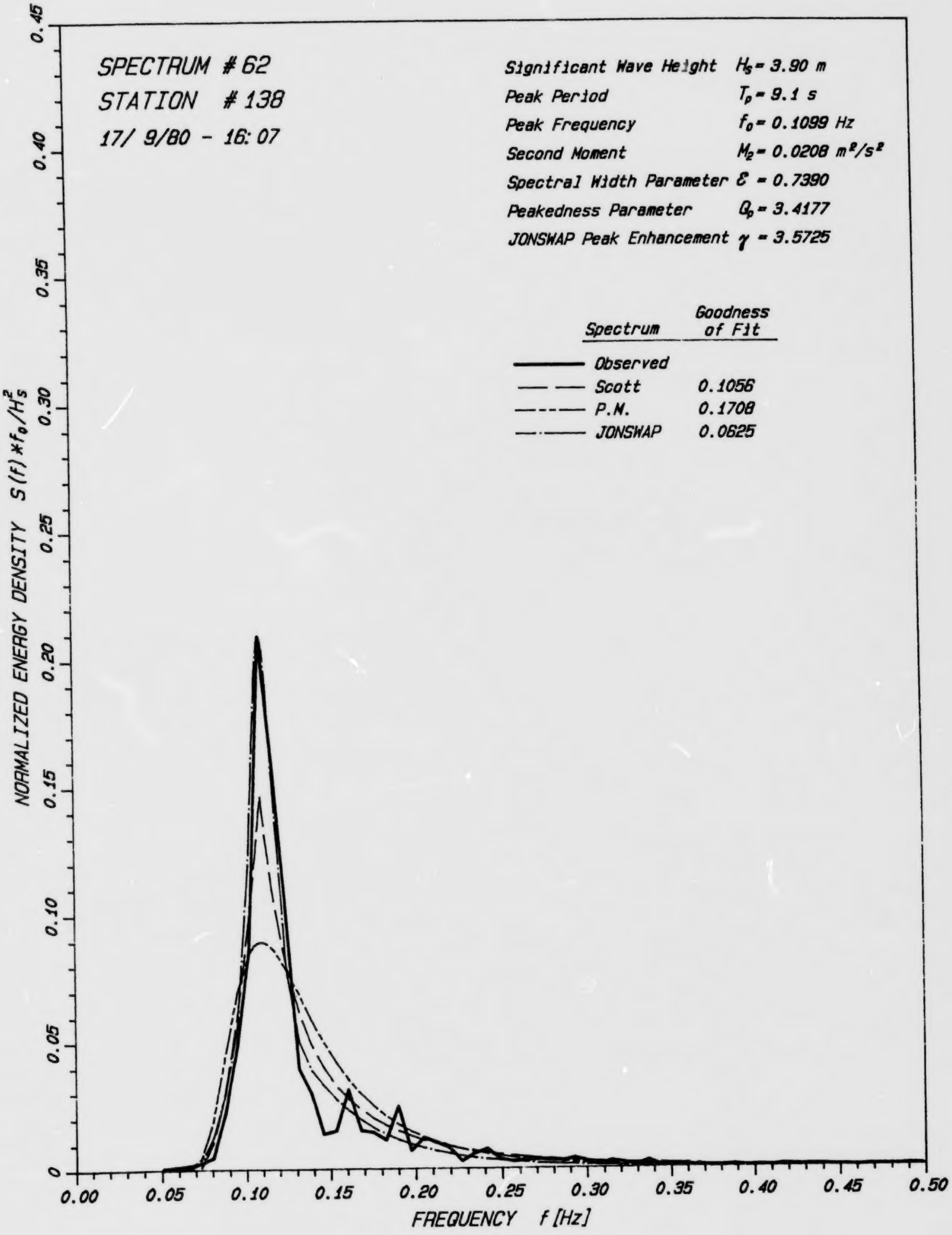

SPECTRUM # 57
STATION # 138
17/ 9/80 - 14:22
Significant Wave Height H_s = 4.19 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0234 m^2/s^2
Spectral Width Parameter ε = 0.7177
Peakedness Parameter Q_p = 3.1550
JONSWAP Peak Enhancement γ = 3.0228
Spectrum
Goodness of Fit
Observed
Scott 0.1506
P.M. 0.1699
JONSWAP 0.1467
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

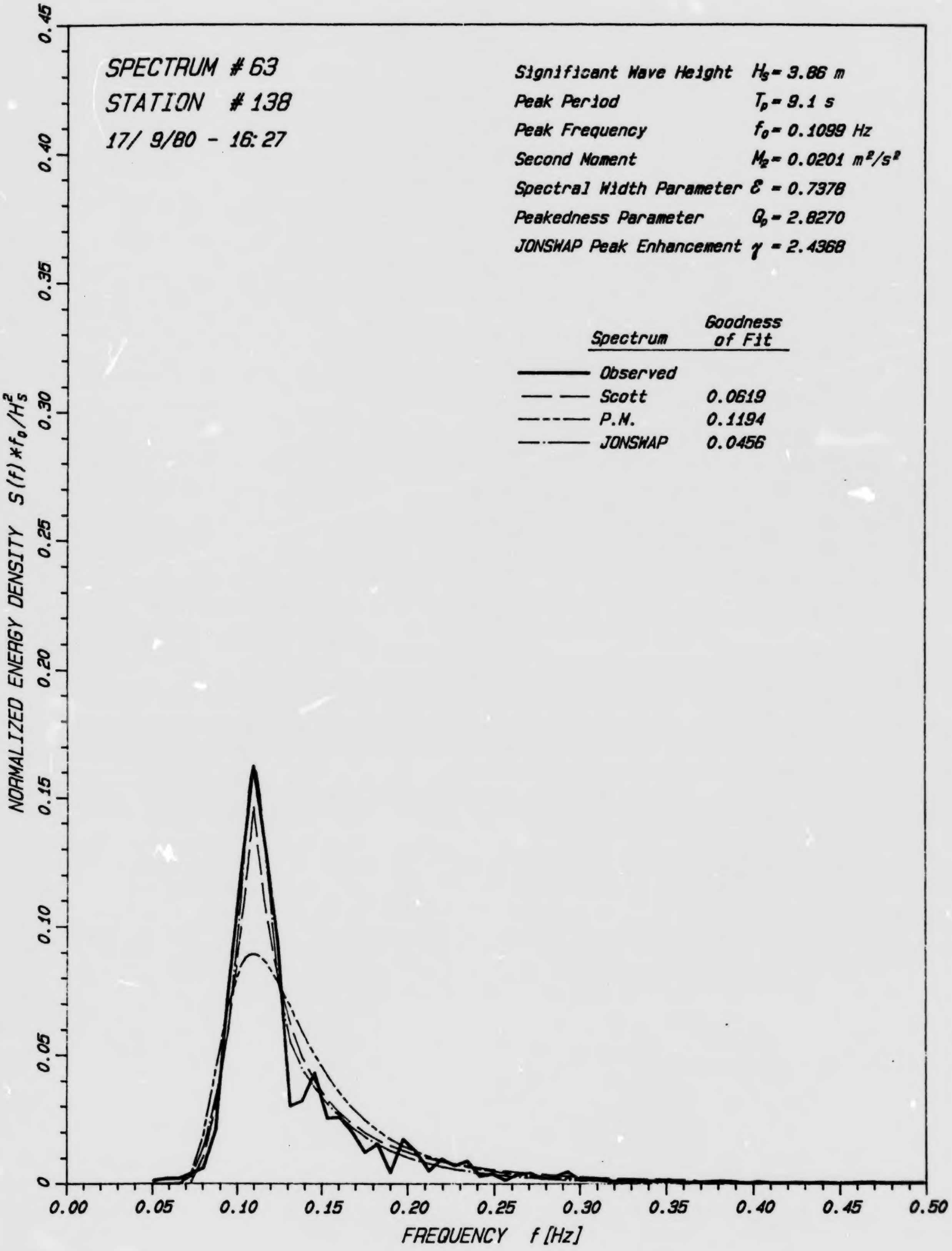

SPECTRUM # 58
STATION # 138
17/ 9/80 - 14: 42
Significant Wave Height H_s = 3.68 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0204 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.7144
Peakedness Parameter Q_p = 2.6212
JONSWAP Peak Enhancement γ = 1.9590
Spectrum
Goodness of Fit
Observed
Scott 0.0725
P.M. 0.1072
JONSWAP 0.0757
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

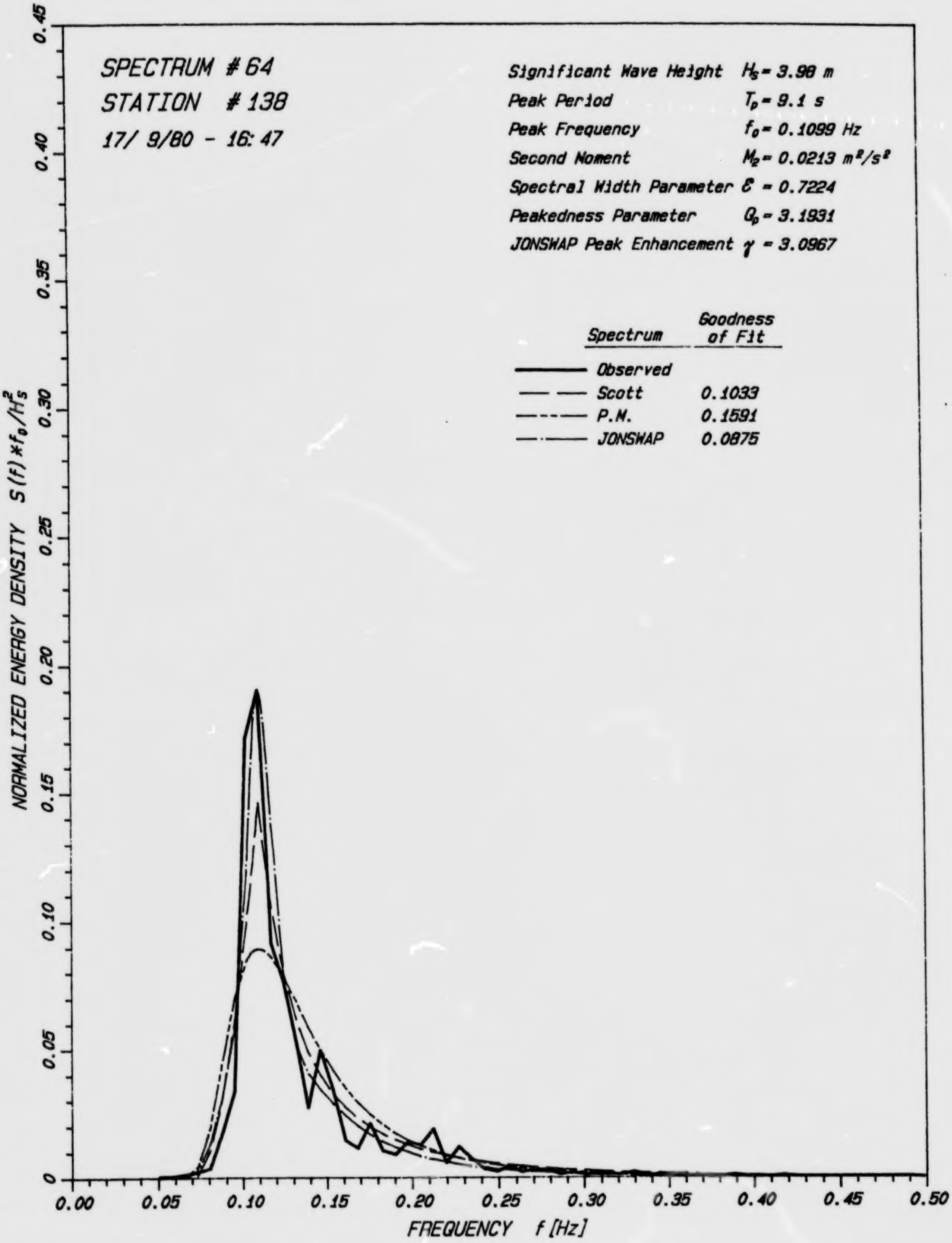

SPECTRUM # 59
STATION # 138
17/ 9/80 - 15: 07
Significant Wave Height H_s= 3.89 m
Peak Period T_p= 9.1 s
Peak Frequency f_0= 0.1099 Hz
Second Moment M_2= 0.0216 m^2/s^2
Spectral Width Parameter ε = 0.7165
Peakedness Parameter Q_p= 2.6378
JONSWAP Peak Enhancement γ = 2.7053
Spectrum
Goodness of Fit
Observed
Scott 0.0567
P.M. 0.1059
JONSWAP 0.0726
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]

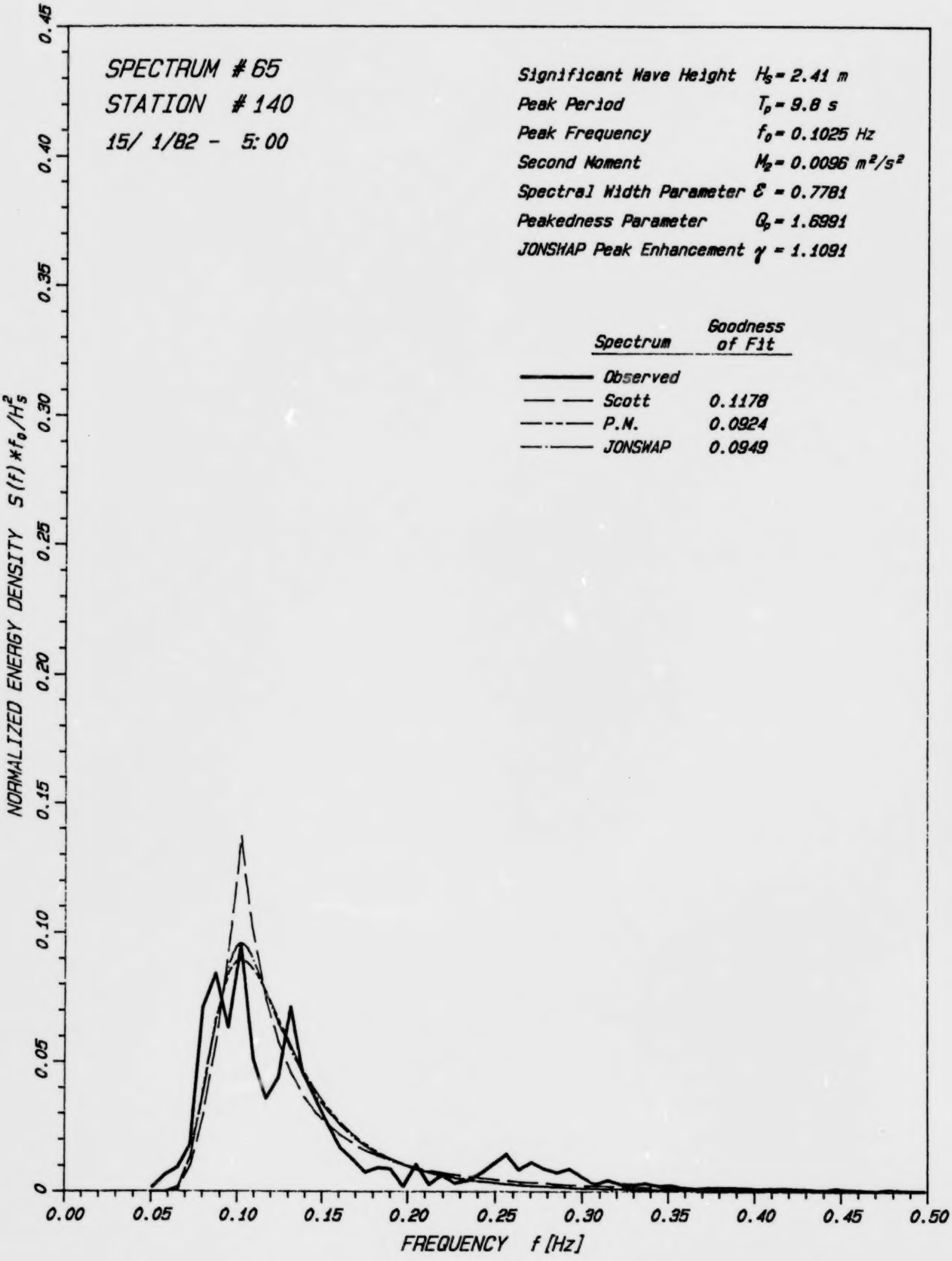

SPECTRUM # 60
STATION # 138
17/ 9/80 - 15: 27
Significant Wave Height H_s = 3.96 m
Peak Period T_p = 8.5 s
Peak Frequency f_0 = 0.1172 Hz
Second Moment M_2 = 0.0215 m^2/s^2
Spectral Width Parameter ε = 0.7312
Peakedness Parameter Q_p = 2.8610
JONSWAP Peak Enhancement γ = 2.5910
Spectrum
Goodness of Fit
Observed
Scott 0.0939
P.M. 0.1278
JONSWAP 0.0953
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

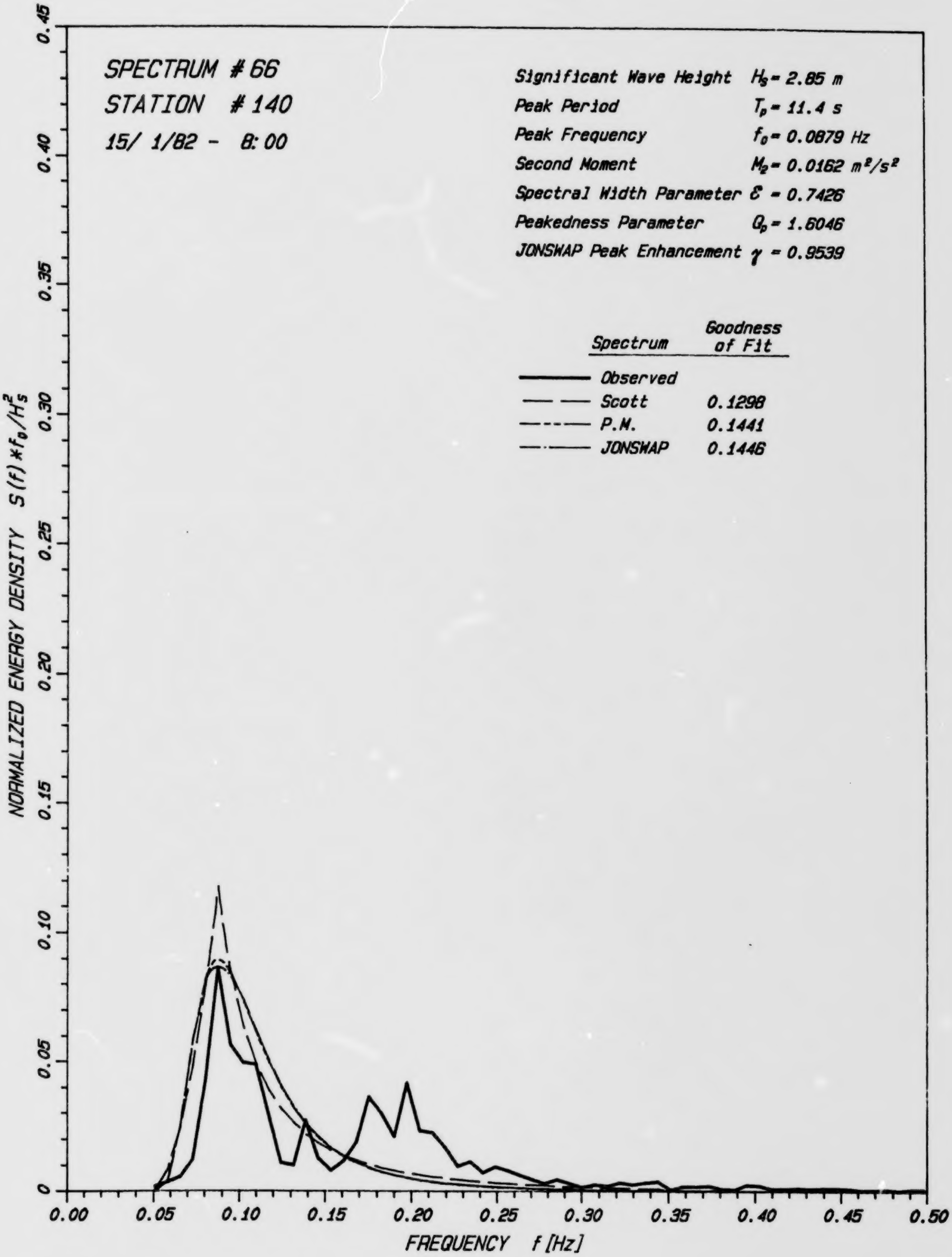

SPECTRUM # 61
STATION # 138
17/ 9/80 - 15: 47
Significant Wave Height H_s = 4.18 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0237 m^2/s^2
Spectral Width Parameter ε = 0.7281
Peakedness Parameter Q_p = 3.0905
JONSWAP Peak Enhancement γ = 2.5254
Spectrum
Goodness of Fit
Observed
Scott 0.0951
P.M. 0.1438
JONSWAP 0.0858
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

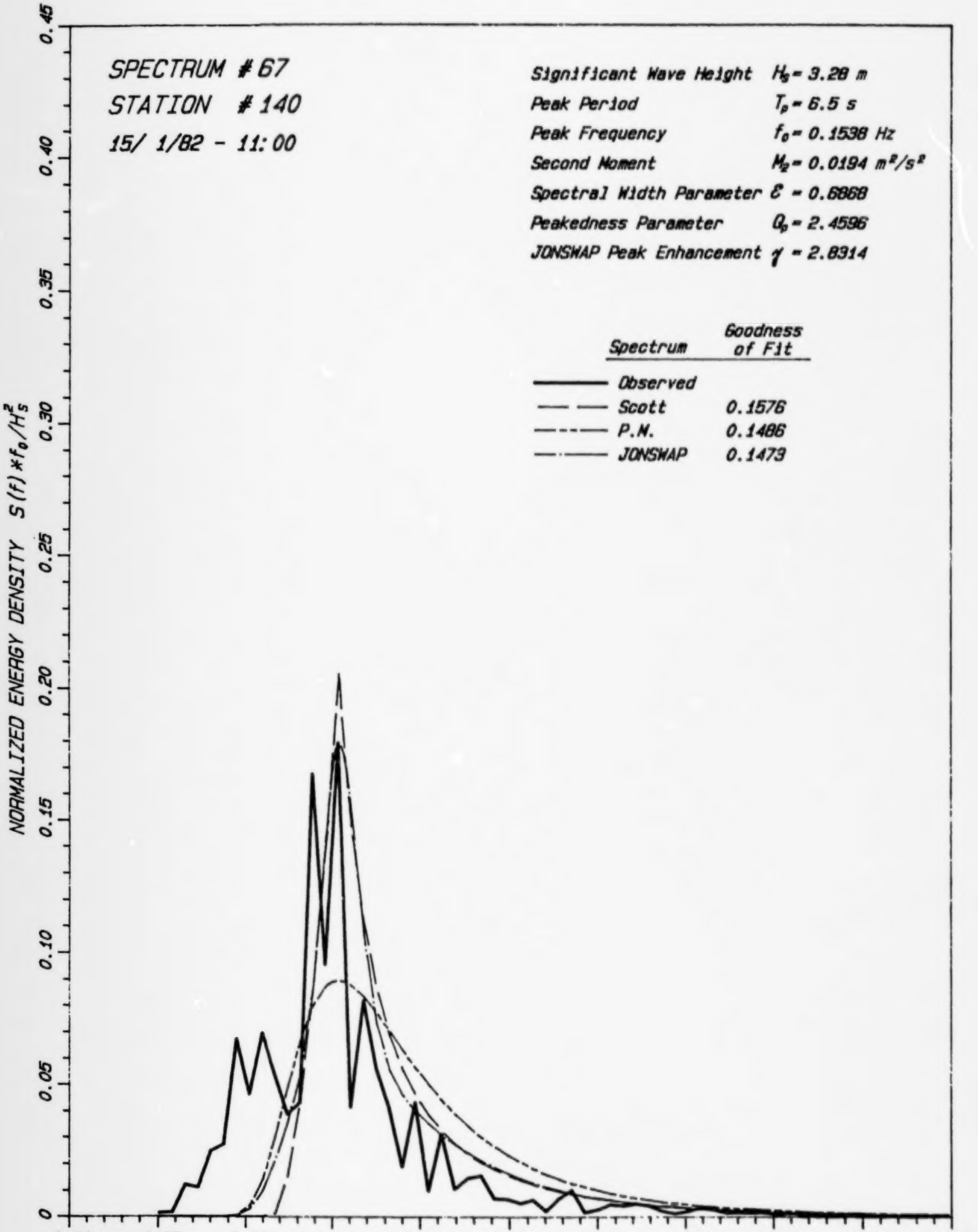

SPECTRUM # 62
STATION # 138
17/ 9/80 - 16: 07
Significant Wave Height H_s = 3.90 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0208 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.7390
Peakedness Parameter Q_p = 3.4177
JONSWAP Peak Enhancement γ = 3.5725
Spectrum
Goodness of Fit
Observed
Scott 0.1056
P.M. 0.1708
JONSWAP 0.0625
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

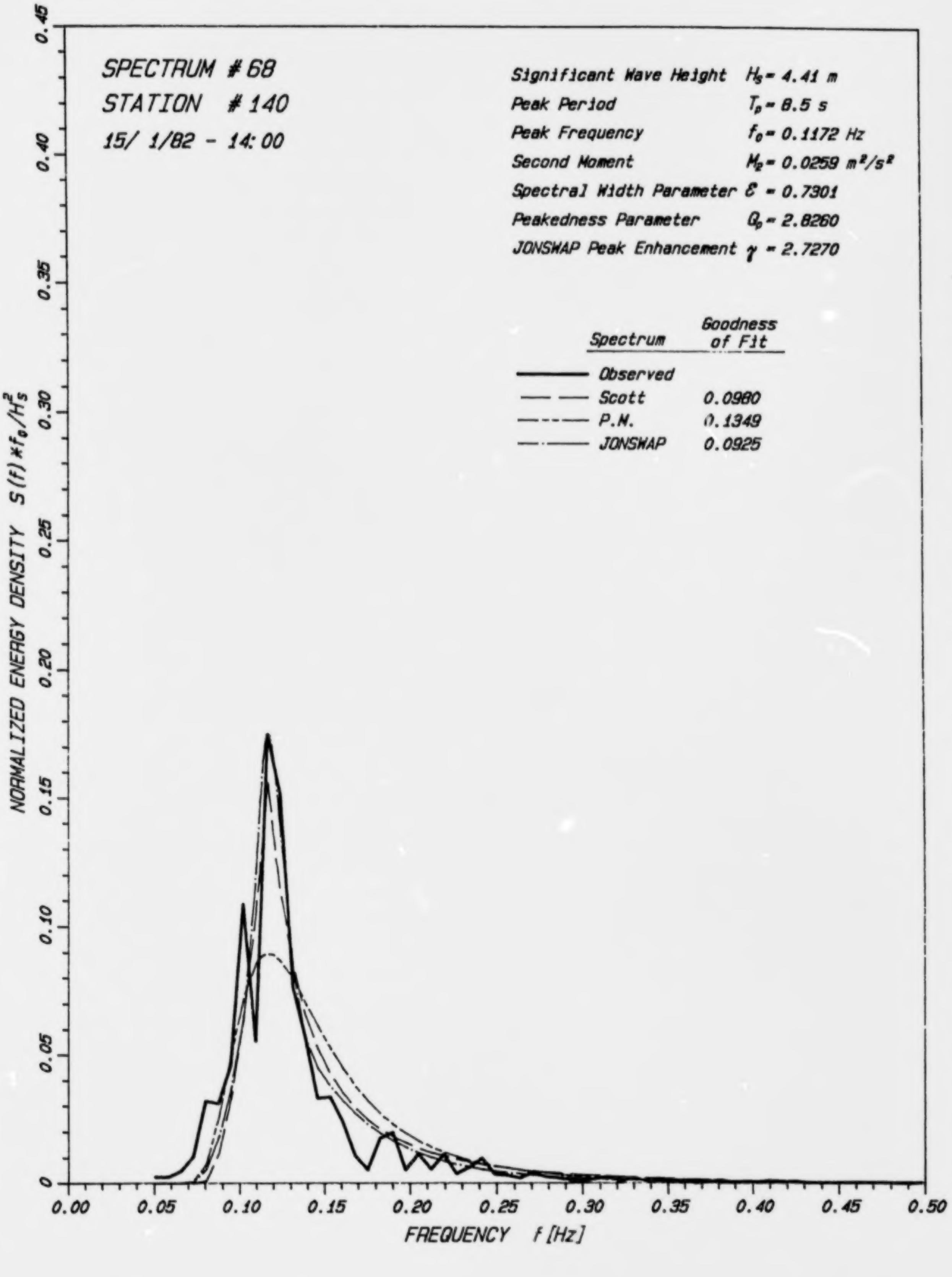

SPECTRUM # 63
STATION # 138
17/ 9/80 - 16: 27
Significant Wave Height H_s = 3.86 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0201 m²/s²
Spectral Width Parameter ε = 0.7378
Peakedness Parameter Q_p = 2.8270
JONSWAP Peak Enhancement γ = 2.4368
Spectrum
Goodness of Fit
Observed
Scott 0.0619
P.M. 0.1194
JONSWAP 0.0456
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

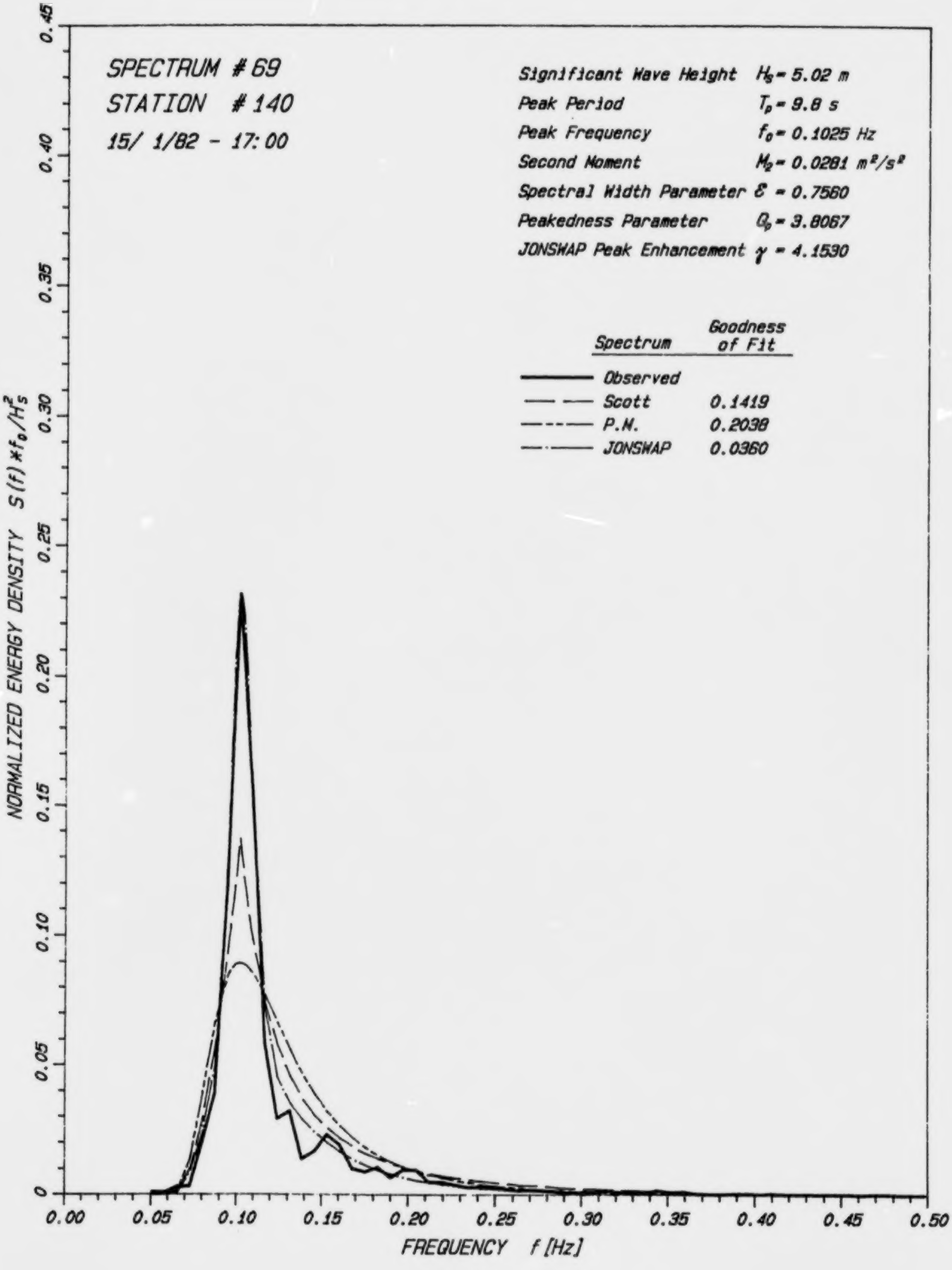

SPECTRUM # 64
STATION # 138
17/ 9/80 - 16: 47
Significant Wave Height H_s = 3.98 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0213 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.7224
Peakedness Parameter Q_p = 3.1931
JONSWAP Peak Enhancement γ = 3.0967
Spectrum
Goodness of Fit
Observed
Scott 0.1033
P.M. 0.1591
JONSWAP 0.0875
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
FREQUENCY f [Hz]
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

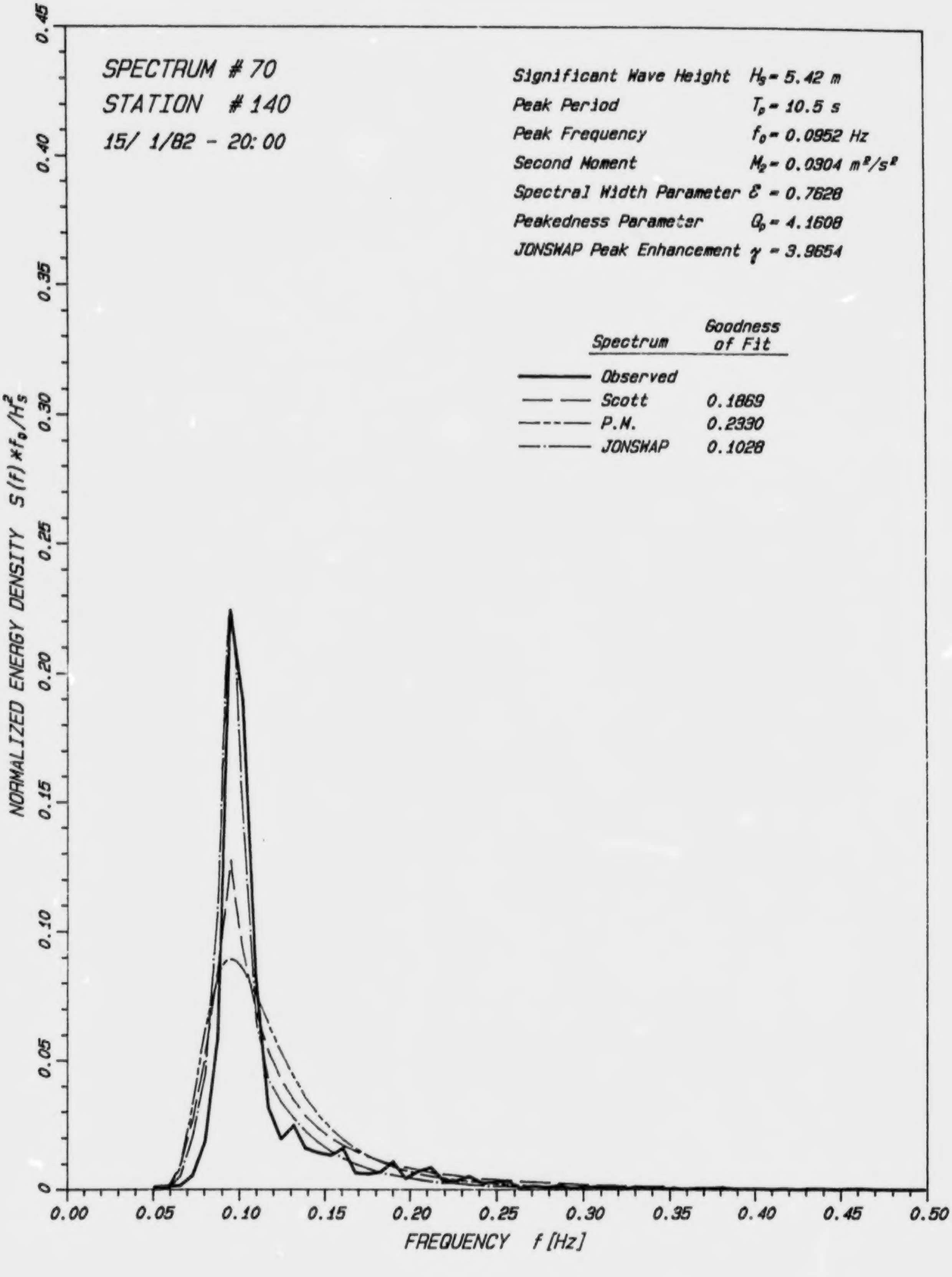

SPECTRUM # 65
STATION # 140
15/ 1/82 - 5:00
Significant Wave Height H_s = 2.41 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0096 m²/s²
Spectral Width Parameter ε = 0.7781
Peakedness Parameter Q_p = 1.6991
JONSWAP Peak Enhancement γ = 1.1091
Spectrum
Goodness of Fit
Observed
Scott 0.1178
P.M. 0.0924
JONSWAP 0.0949
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

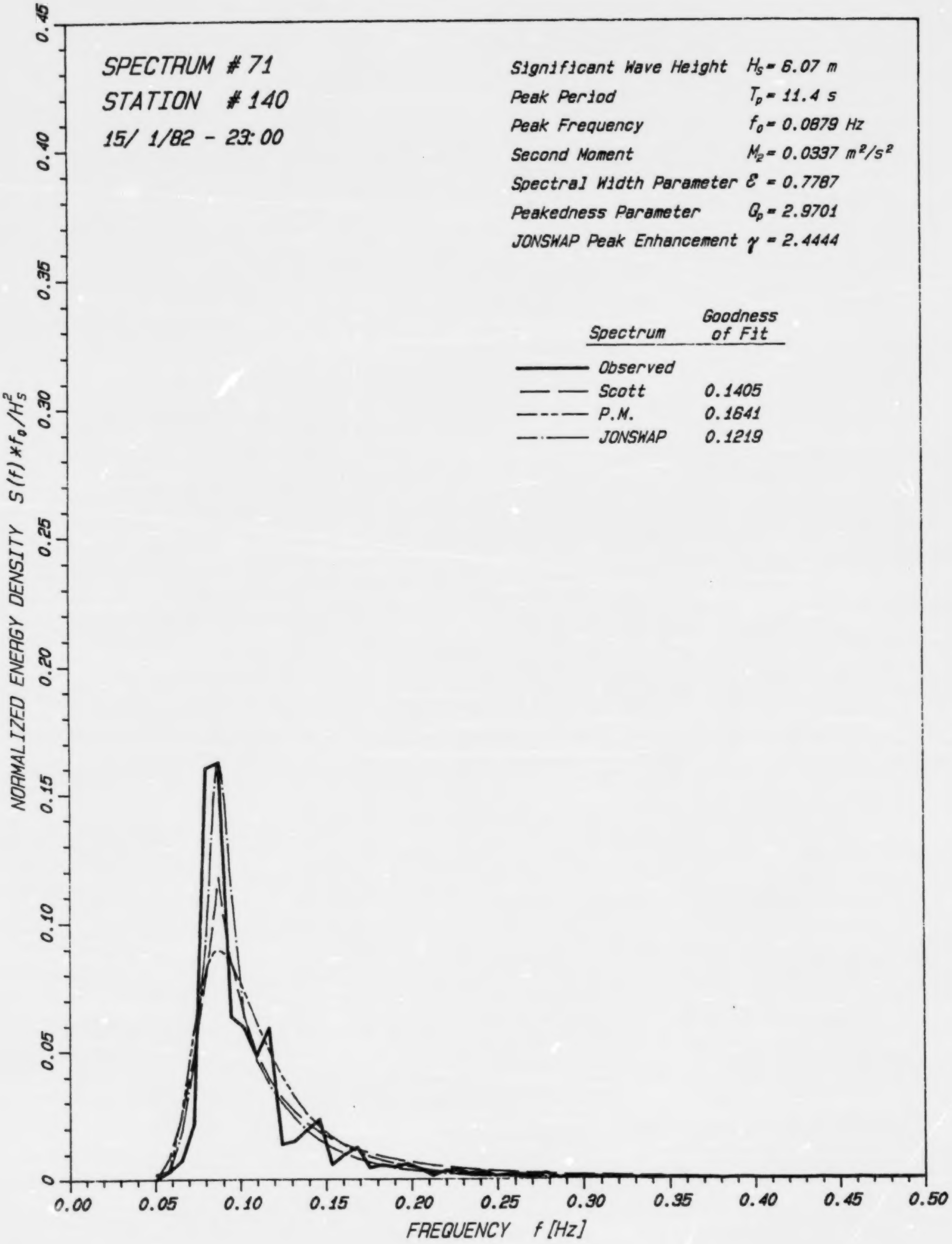

SPECTRUM # 66
STATION # 140
15/ 1/82 - 8:00
Significant Wave Height H_s = 2.85 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0162 m^2/s^2
Spectral Width Parameter ε = 0.7426
Peakedness Parameter Q_p = 1.6046
JONSWAP Peak Enhancement γ = 0.9539
Spectrum
Goodness of Fit
Observed
Scott 0.1298
P.M. 0.1441
JONSWAP 0.1446
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

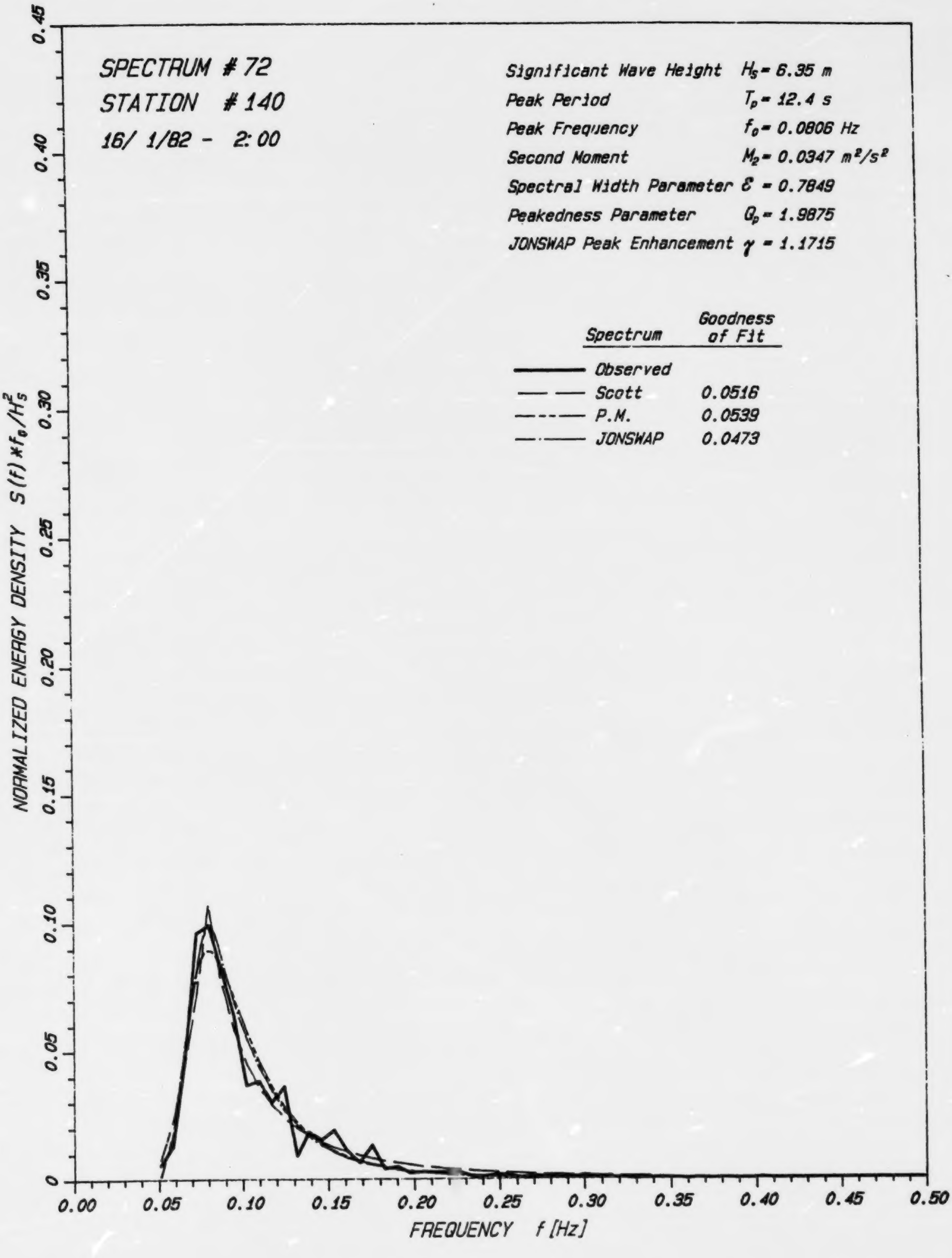

SPECTRUM # 67
STATION # 140
15/ 1/82 - 11:00
Significant Wave Height H_s = 3.28 m
Peak Period T_p = 6.5 s
Peak Frequency f_0 = 0.1538 Hz
Second Moment M_2 = 0.0194 m^2/s^2
Spectral Width Parameter ε = 0.6868
Peakedness Parameter Q_p = 2.4596
JONSWAP Peak Enhancement γ = 2.8314
Spectrum
Goodness of Fit
Observed
Scott 0.1576
P.M. 0.1486
JONSWAP 0.1473
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

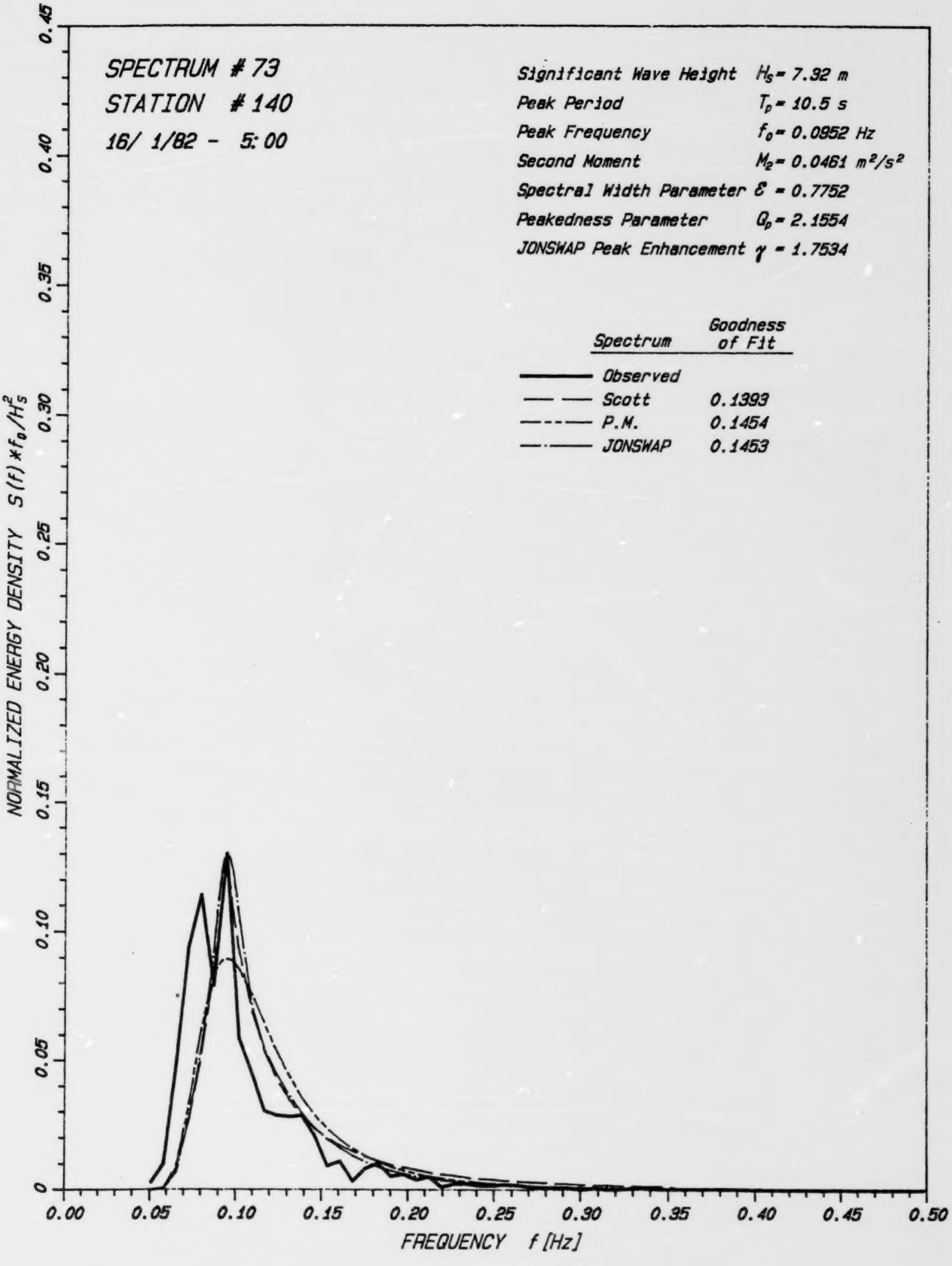

SPECTRUM # 68
STATION # 140
15/ 1/82 - 14:00
Significant Wave Height H_s = 4.41 m
Peak Period T_p = 8.5 s
Peak Frequency f_0 = 0.1172 Hz
Second Moment M_2 = 0.0259 m^2/s^2
Spectral Width Parameter ε = 0.7301
Peakedness Parameter Q_p = 2.8260
JONSWAP Peak Enhancement γ = 2.7270
Spectrum
Goodness of Fit
Observed
Scott 0.0980
P.M. 0.1349
JONSWAP 0.0925
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

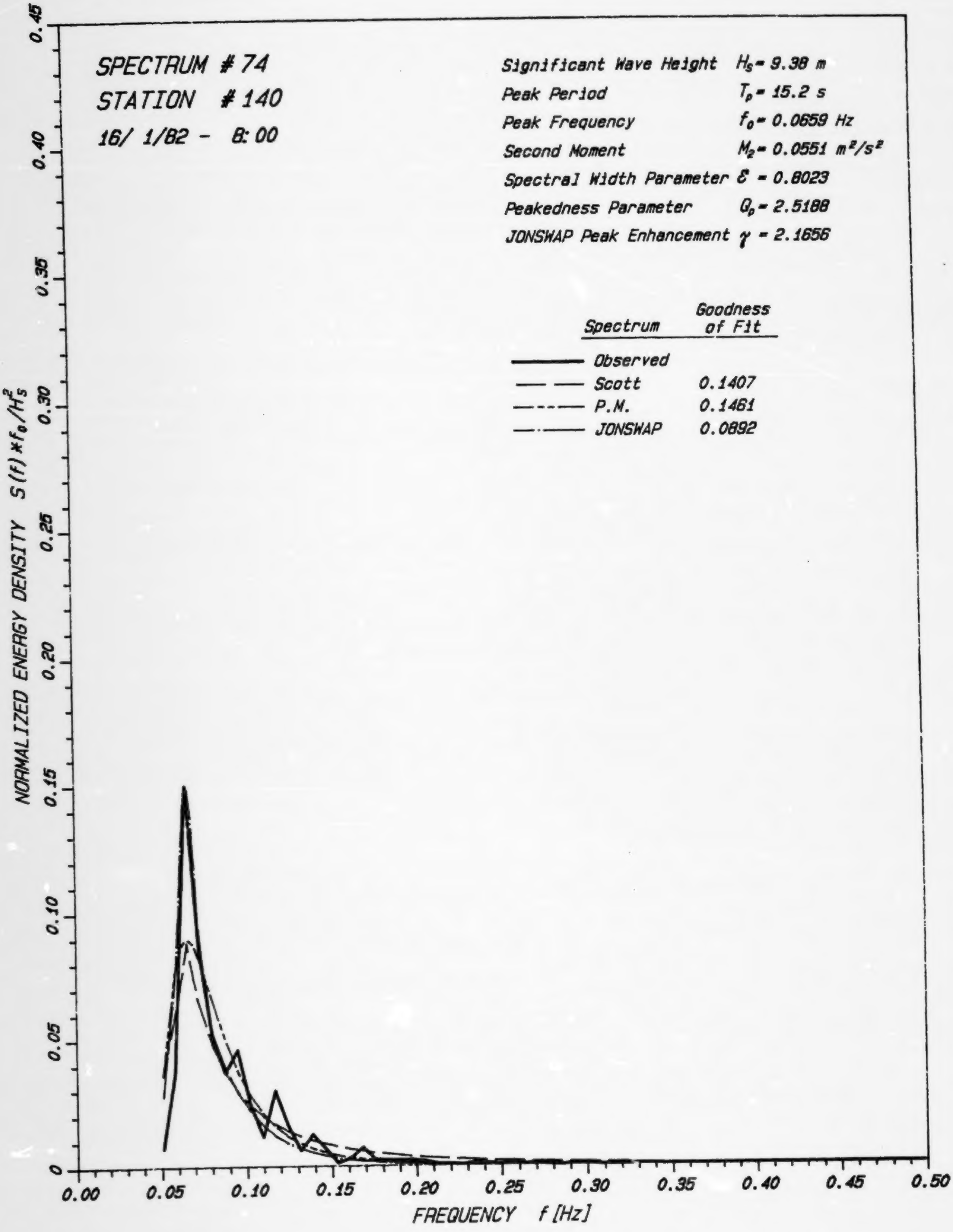

SPECTRUM # 69
STATION # 140
15/ 1/82 - 17: 00
Significant Wave Height H_s = 5.02 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0281 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.7560
Peakedness Parameter Q_p = 3.8067
JONSWAP Peak Enhancement γ = 4.1530
Spectrum
Goodness of Fit
Observed
Scott 0.1419
P.M. 0.2038
JONSWAP 0.0360
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

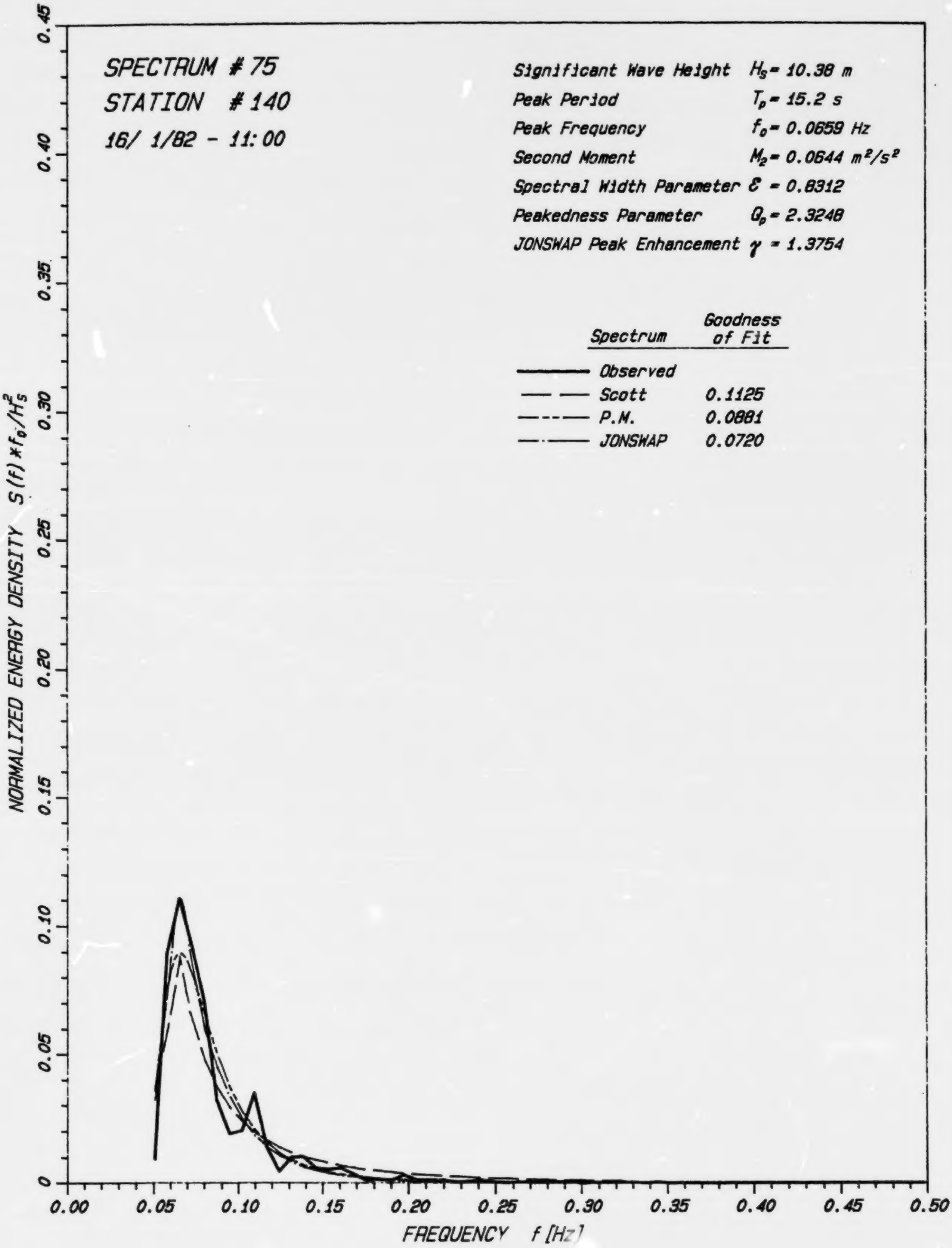

SPECTRUM # 70
STATION # 140
15/ 1/82 - 20: 00
Significant Wave Height H_s = 5.42 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0304 m^2/s^2
Spectral Width Parameter ε = 0.7628
Peakedness Parameter Q_p = 4.1608
JONSWAP Peak Enhancement γ = 3.9654
Spectrum
Goodness of Fit
Observed
Scott 0.1869
P.M. 0.2330
JONSWAP 0.1028
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

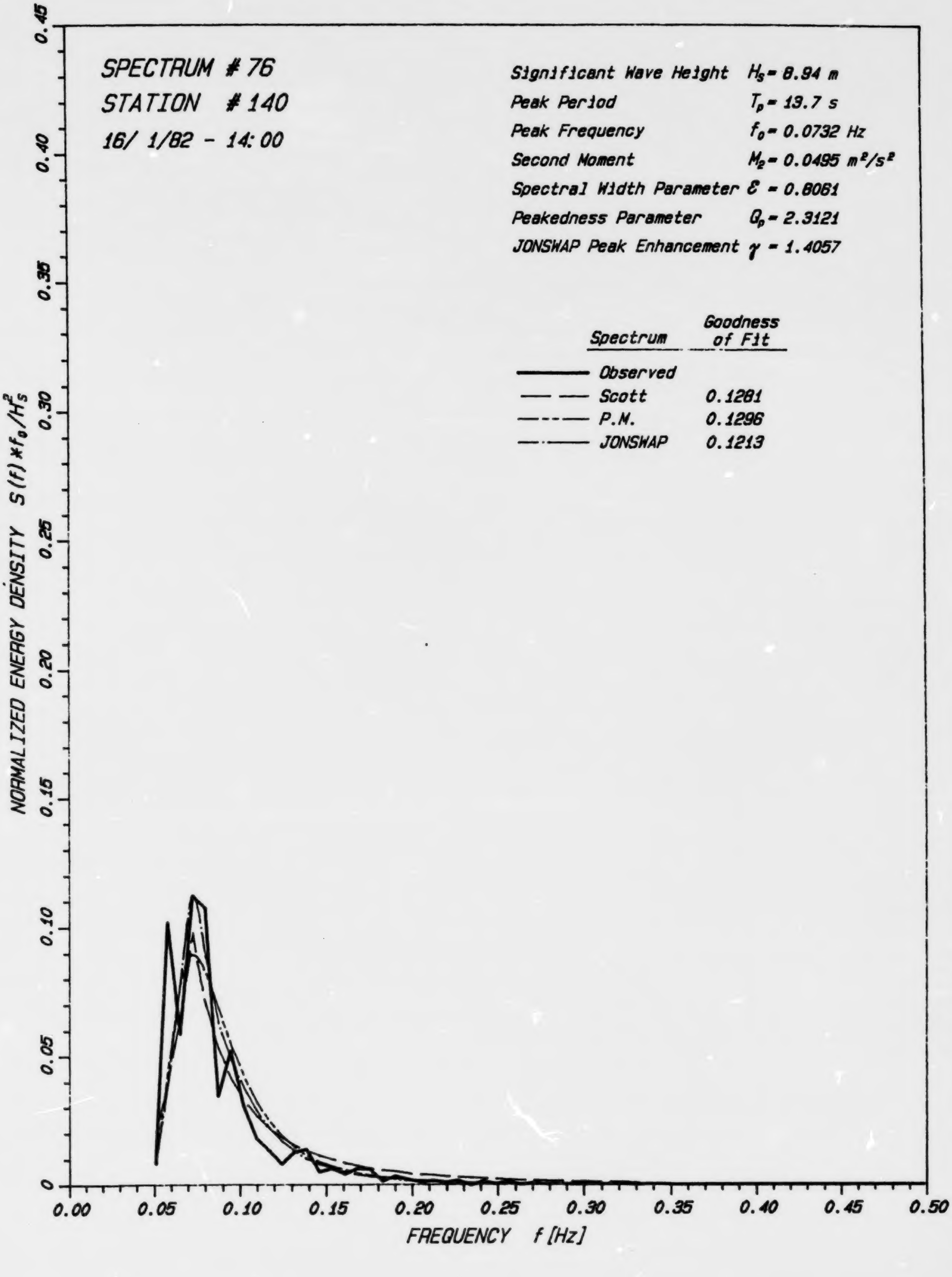

SPECTRUM # 71
STATION # 140
15/ 1/82 - 23:00
Significant Wave Height H_s = 6.07 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0337 m^2/s^2
Spectral Width Parameter ε = 0.7787
Peakedness Parameter Q_p = 2.9701
JONSWAP Peak Enhancement γ = 2.4444
Spectrum
Goodness of Fit
Observed
Scott 0.1405
P.M. 0.1641
JONSWAP 0.1219
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45
FREQUENCY f [Hz]
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50

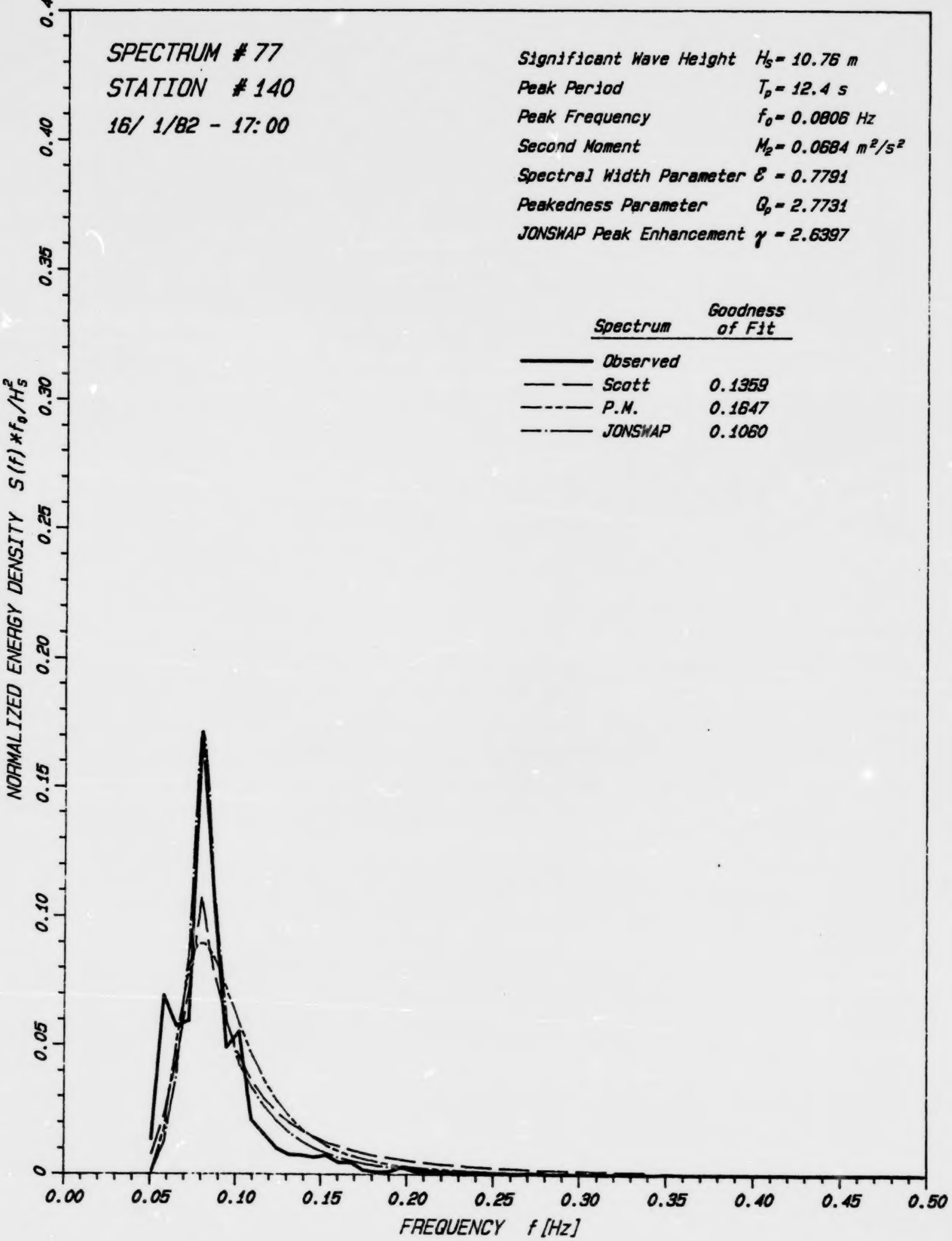

SPECTRUM # 72
STATION # 140
16/ 1/82 - 2:00
Significant Wave Height H_s = 6.35 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0347 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.7849
Peakedness Parameter Q_p = 1.9875
JONSWAP Peak Enhancement γ = 1.1715
Spectrum
Goodness of Fit
Observed
Scott 0.0516
P.M. 0.0539
JONSWAP 0.0473
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

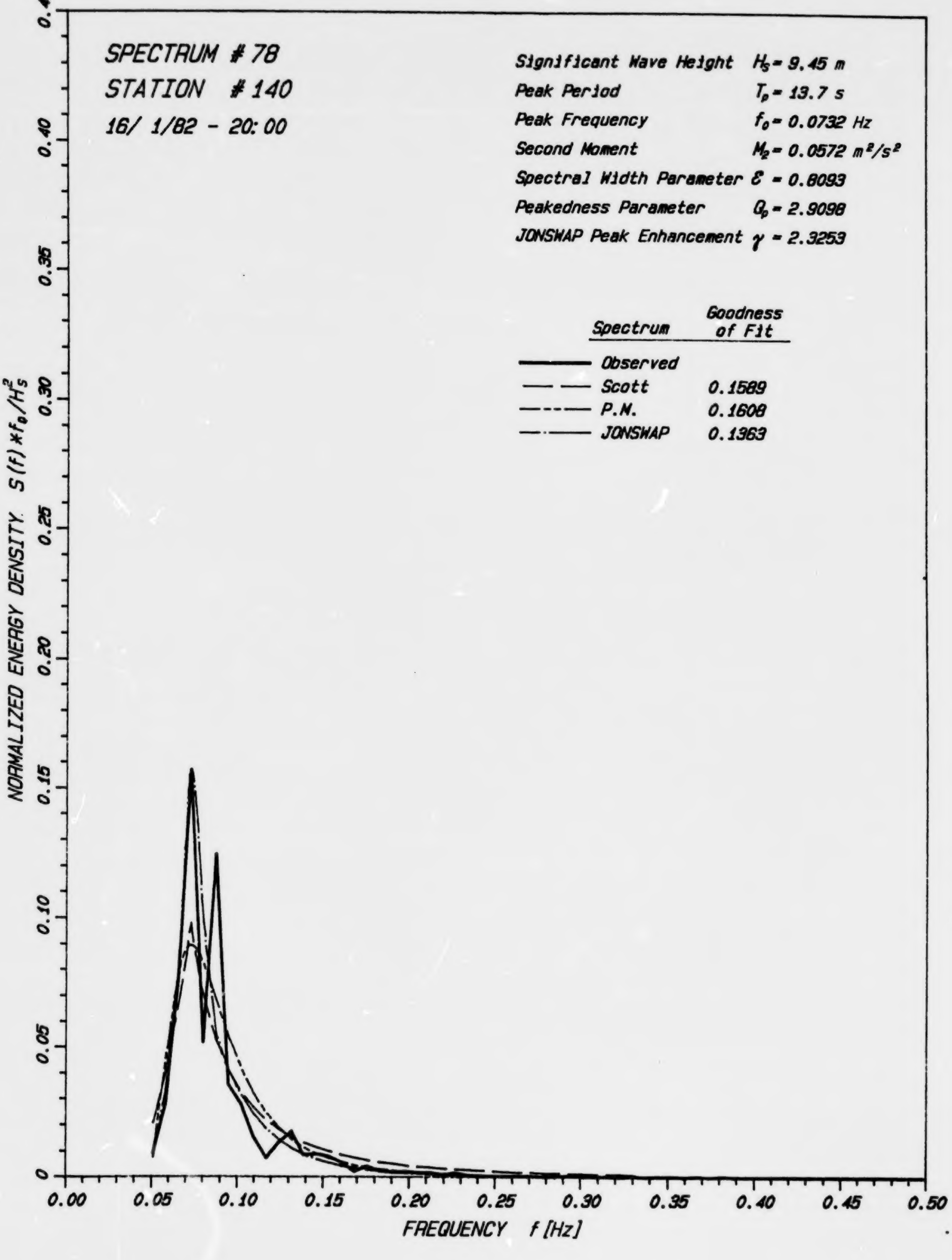

SPECTRUM # 73
STATION # 140
16/ 1/82 - 5:00
Significant Wave Height H_s = 7.32 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0461 m^2/s^2
Spectral Width Parameter ε = 0.7752
Peakedness Parameter Q_p = 2.1554
JONSWAP Peak Enhancement γ = 1.7534
Spectrum
Goodness of Fit
Observed
Scott 0.1393
P.M. 0.1454
JONSWAP 0.1453
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

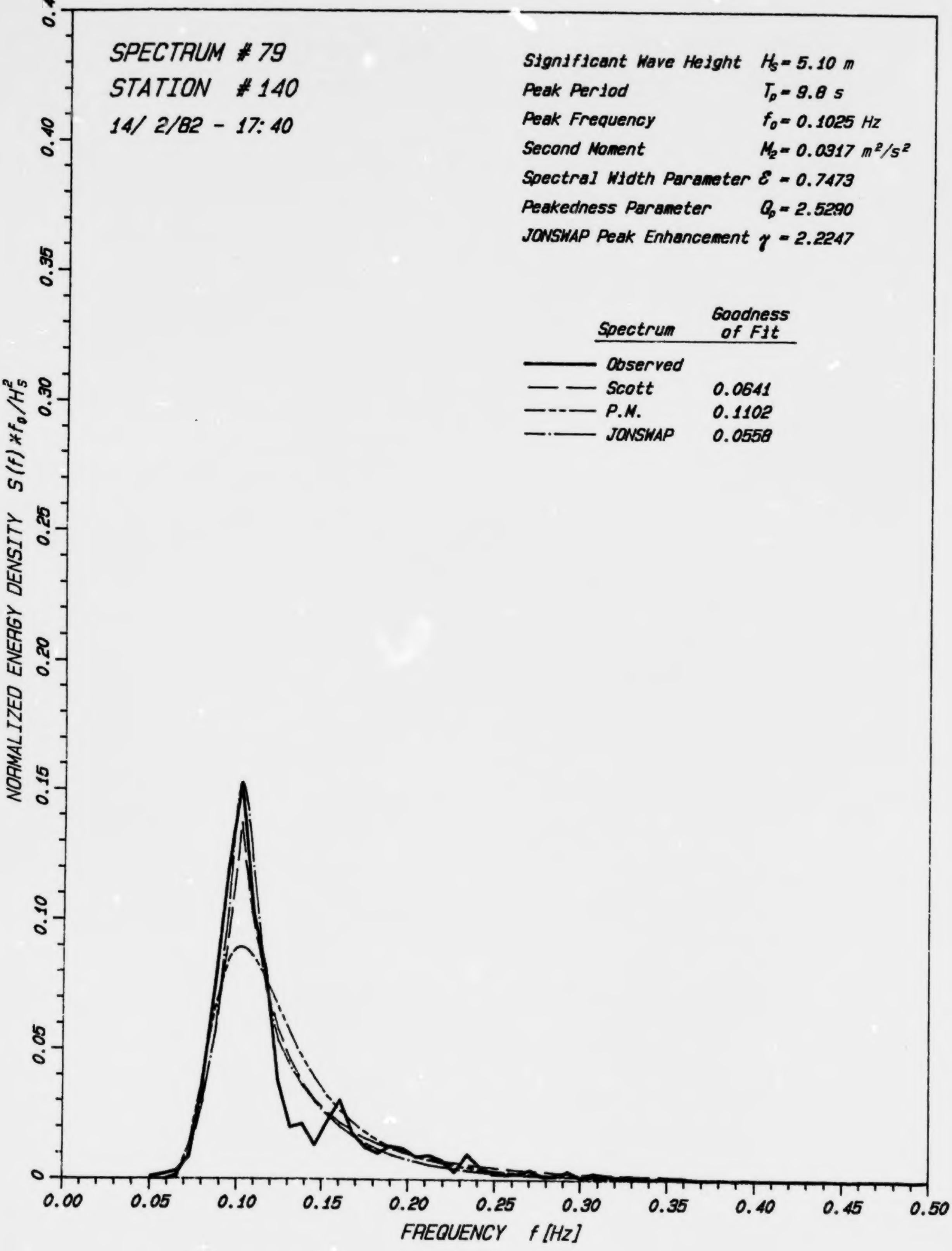

SPECTRUM # 74
STATION # 140
16/ 1/82 - 8: 00
Significant Wave Height H_s = 9.38 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0551 m^2/s^2
Spectral Width Parameter ε = 0.8023
Peakedness Parameter Q_p = 2.5188
JONSWAP Peak Enhancement γ = 2.1656
Spectrum
Goodness of Fit
Observed
Scott 0.1407
P.M. 0.1461
JONSWAP 0.0892
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

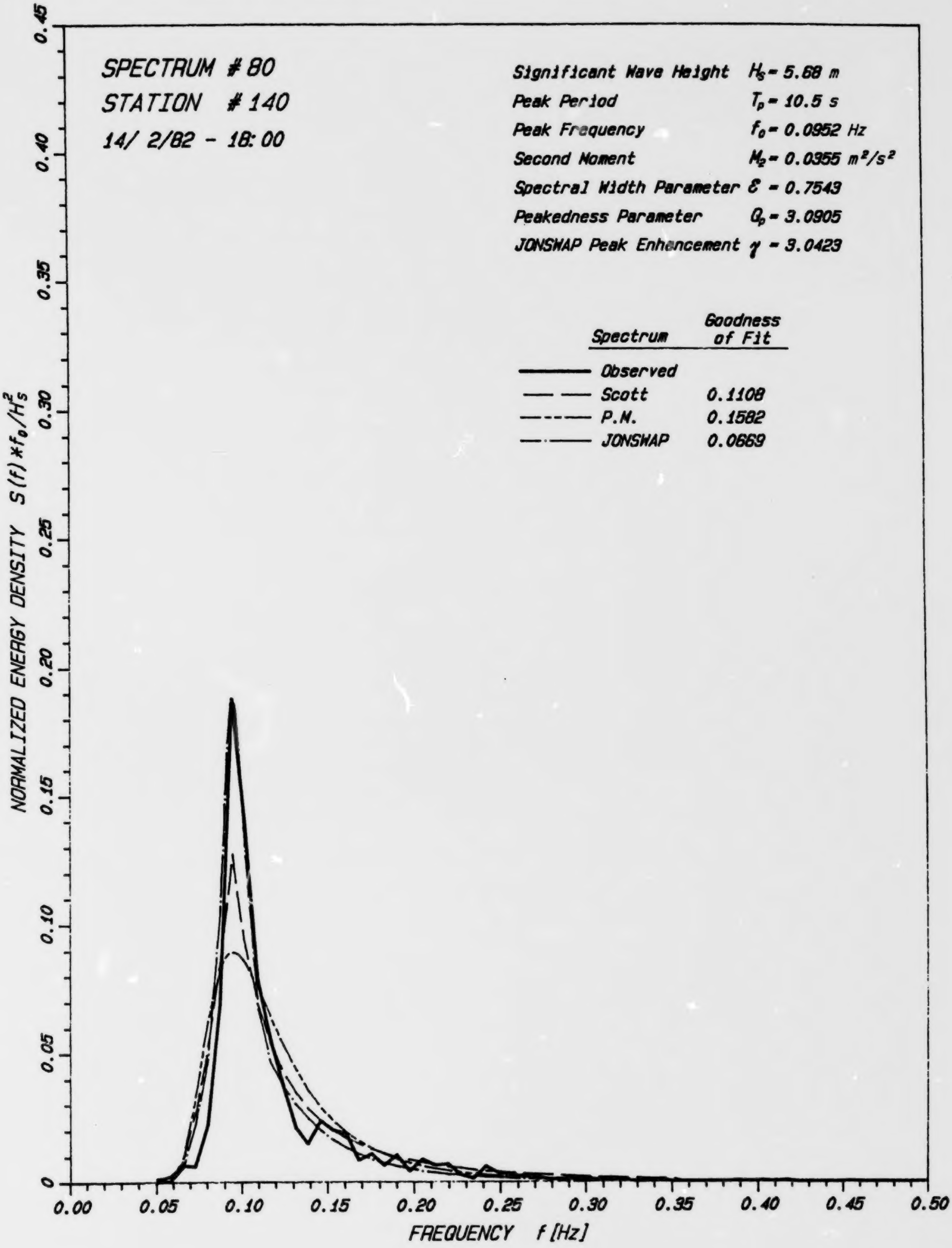

SPECTRUM # 75
STATION # 140
16/ 1/82 - 11: 00
Significant Wave Height H_s = 10.38 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0644 m²/s²
Spectral Width Parameter ε = 0.8312
Peakedness Parameter Q_p = 2.3248
JONSWAP Peak Enhancement γ = 1.3754
Spectrum
Goodness of Fit
Observed
Scott 0.1125
P.M. 0.0881
JONSWAP 0.0720
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]

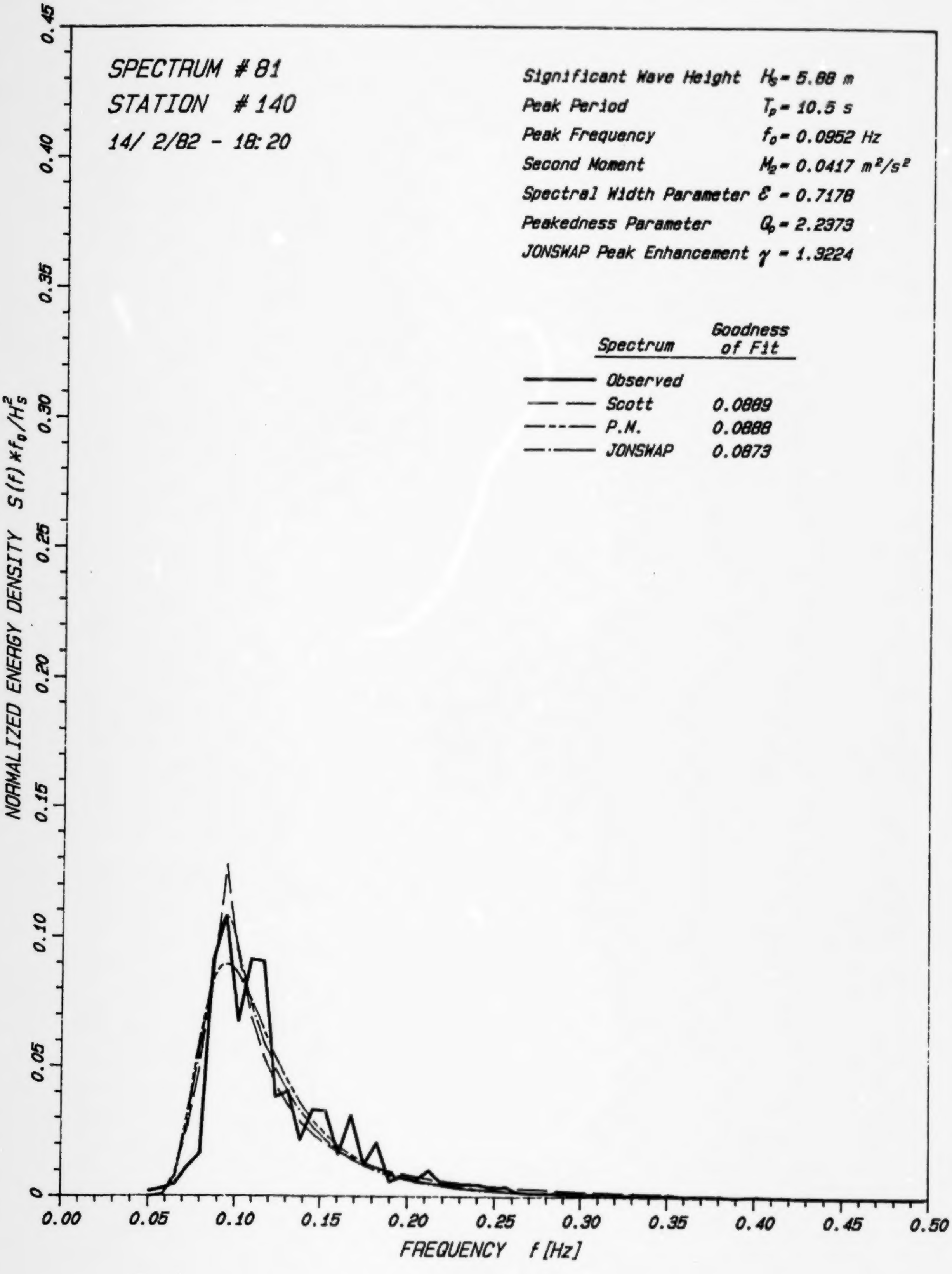

SPECTRUM # 76
STATION # 140
16/ 1/82 - 14:00
Significant Wave Height H_s = 8.94 m
Peak Period T_p = 13.7 s
Peak Frequency f_0 = 0.0732 Hz
Second Moment M_2 = 0.0495 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.8061
Peakedness Parameter Q_p = 2.3121
JONSWAP Peak Enhancement γ = 1.4057
Spectrum
Goodness of Fit
Observed
Scott 0.1281
P.M. 0.1296
JONSWAP 0.1213
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]

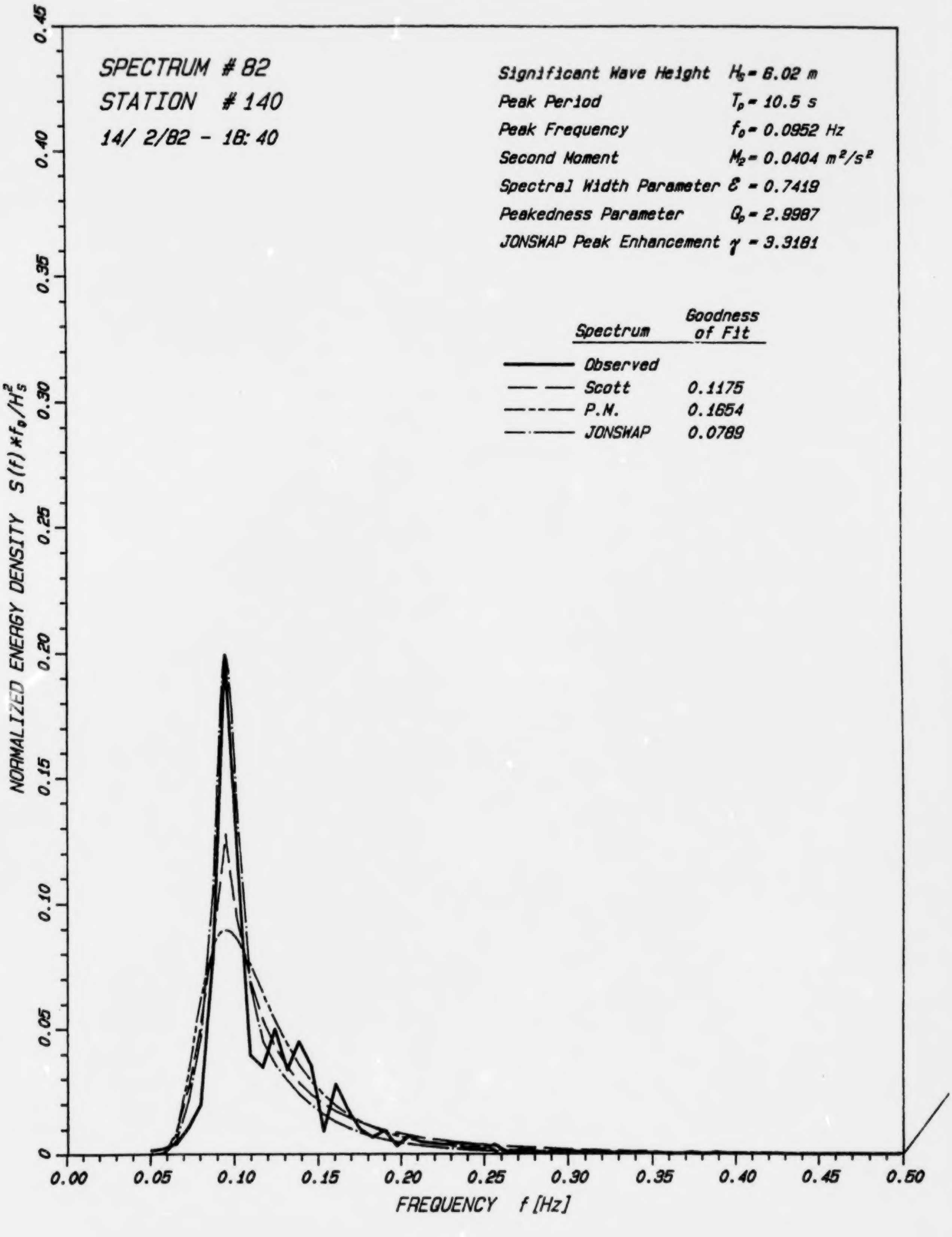

SPECTRUM # 77
STATION # 140
16/ 1/82 - 17: 00
Significant Wave Height H_s = 10.76 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0684 m^2/s^2
Spectral Width Parameter ε = 0.7791
Peakedness Parameter Q_p = 2.7731
JONSWAP Peak Enhancement γ = 2.6397
Spectrum
Goodness of Fit
Observed
Scott 0.1359
P.M. 0.1647
JONSWAP 0.1060
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.50
FREQUENCY f [Hz]


SPECTRUM # 78
STATION # 140
16/ 1/82 - 20:00
Significant Wave Height $H_s = 9.45$ m
Peak Period $T_p = 13.7$ s
Peak Frequency $f_0 = 0.0732$ Hz
Second Moment $M_2 = 0.0572$ m²/s²
Spectral Width Parameter $\varepsilon = 0.8093$
Peakedness Parameter $Q_p = 2.9098$
JONSWAP Peak Enhancement $\gamma = 2.3253$
Spectrum
Goodness of Fit
Observed
Scott 0.1589
P.M. 0.1608
JONSWAP 0.1363
NORMALIZED ENERGY DENSITY. $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

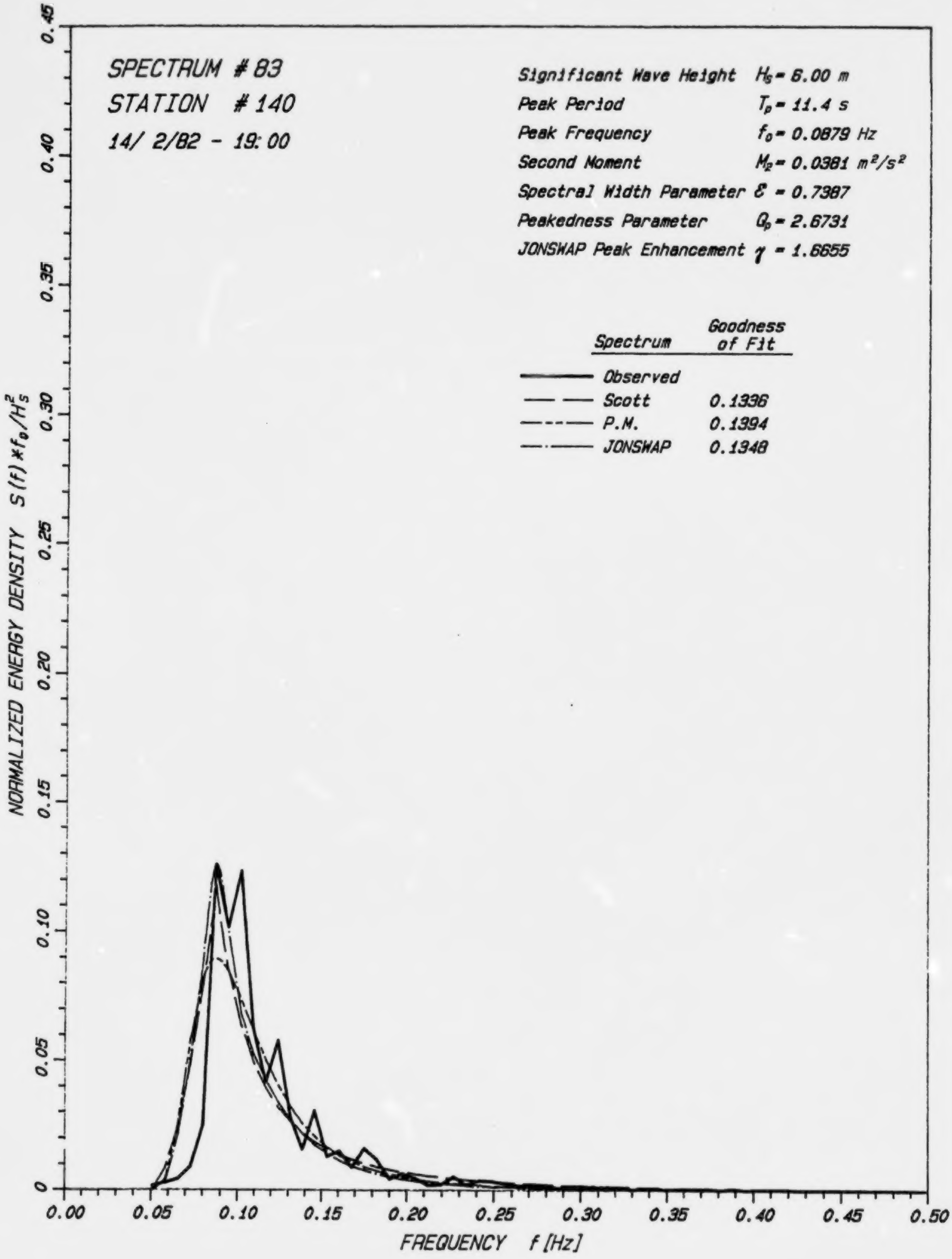

SPECTRUM # 79
STATION # 140
14/ 2/82 - 17: 40
Significant Wave Height H_s = 5.10 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0317 m^2/s^2
Spectral Width Parameter ε = 0.7473
Peakedness Parameter Q_p = 2.5290
JONSWAP Peak Enhancement γ = 2.2247
Spectrum
Goodness of Fit
Observed
Scott 0.0641
P.M. 0.1102
JONSWAP 0.0558
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

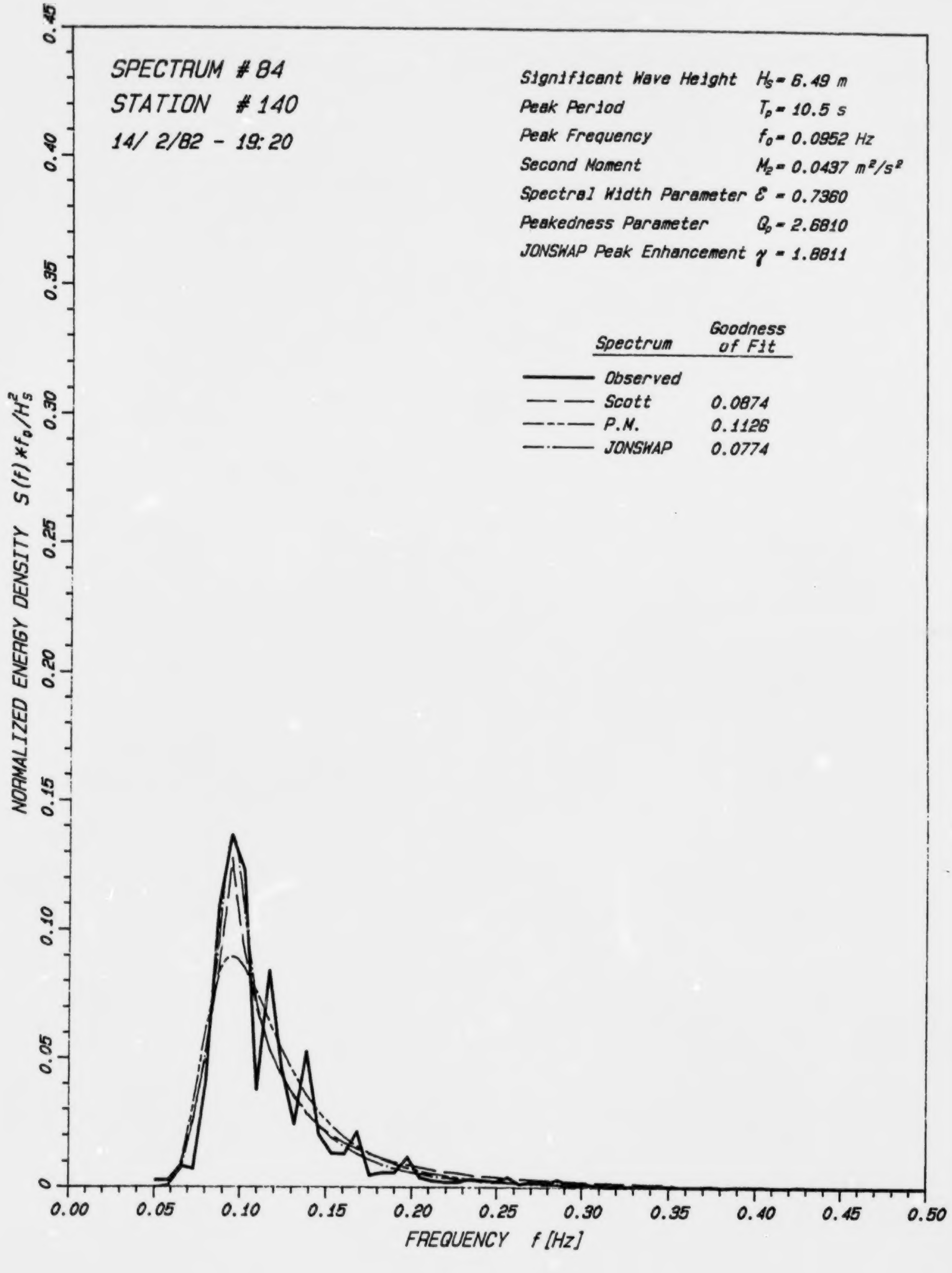

SPECTRUM # 80
STATION # 140
14/ 2/82 - 18:00
Significant Wave Height H_s = 5.68 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0355 m²/s²
Spectral Width Parameter ε = 0.7543
Peakedness Parameter Q_p = 3.0905
JONSWAP Peak Enhancement γ = 3.0423
Spectrum
Goodness of Fit
Observed
Scott 0.1108
P.M. 0.1582
JONSWAP 0.0669
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

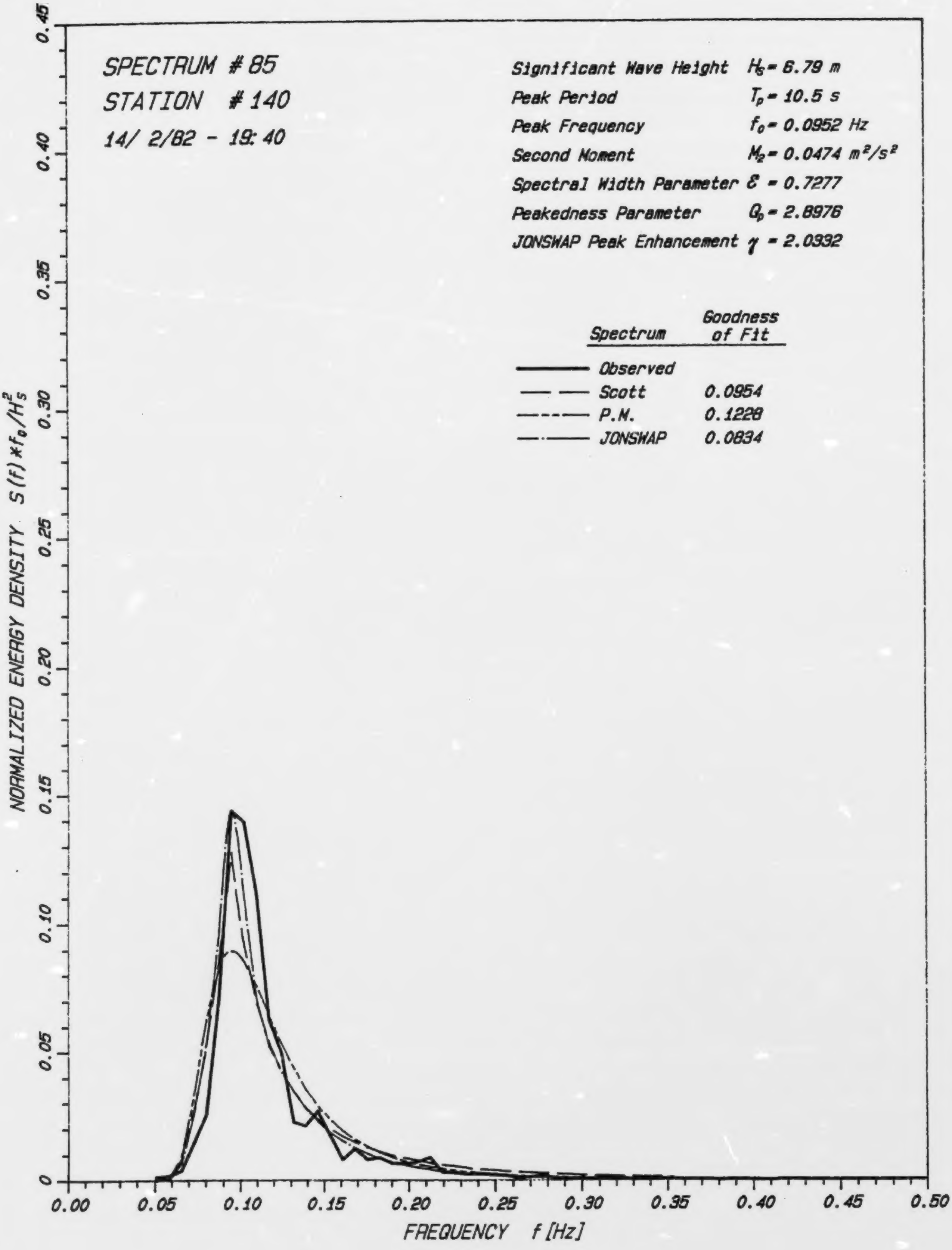

SPECTRUM # 81
STATION # 140
14/ 2/82 - 18:20
Significant Wave Height H_s = 5.88 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0417 m^2/s^2
Spectral Width Parameter ε = 0.7178
Peakedness Parameter Q_p = 2.2373
JONSWAP Peak Enhancement γ = 1.3224
Spectrum
Goodness of Fit
Observed
Scott 0.0889
P.N. 0.0888
JONSWAP 0.0873
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

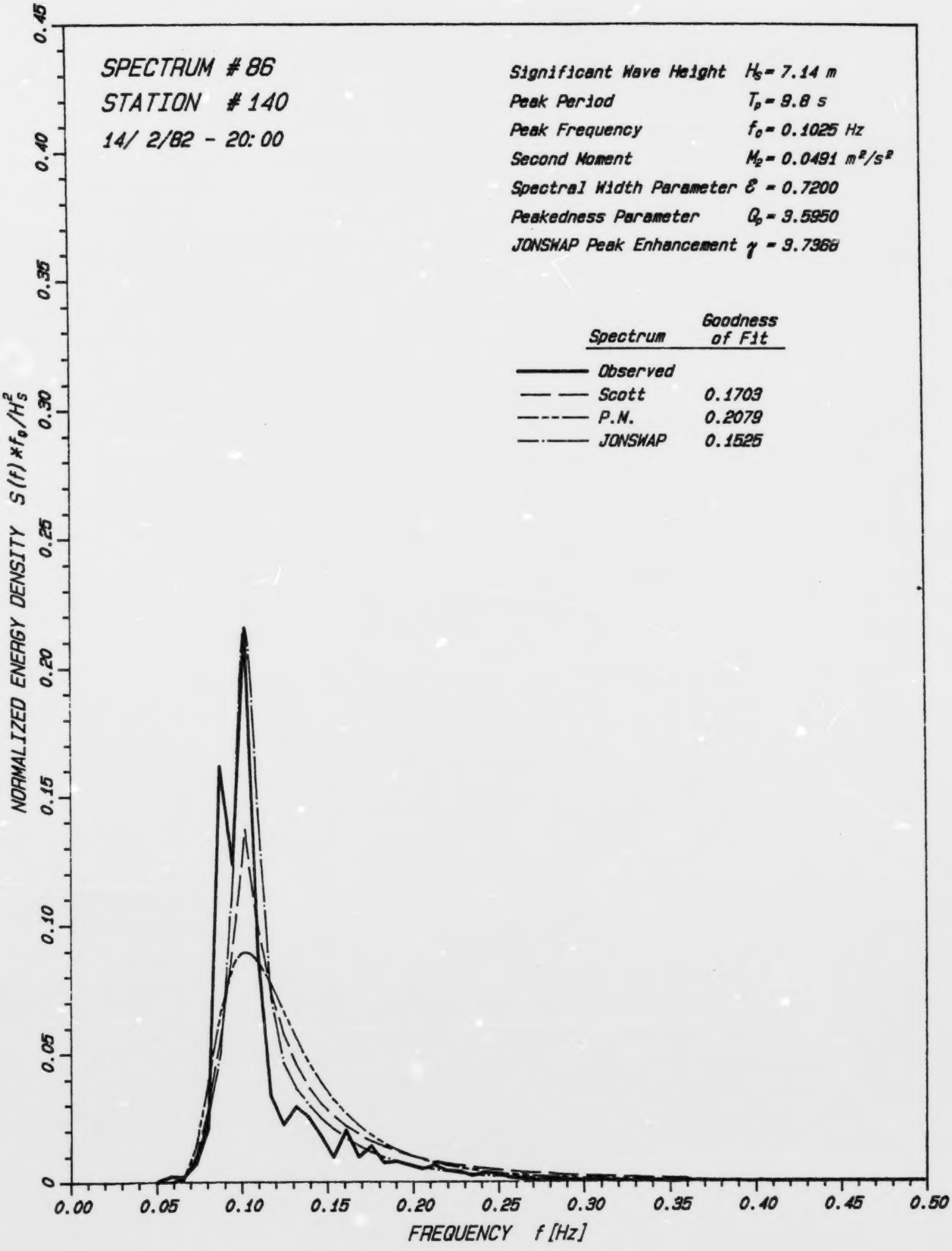


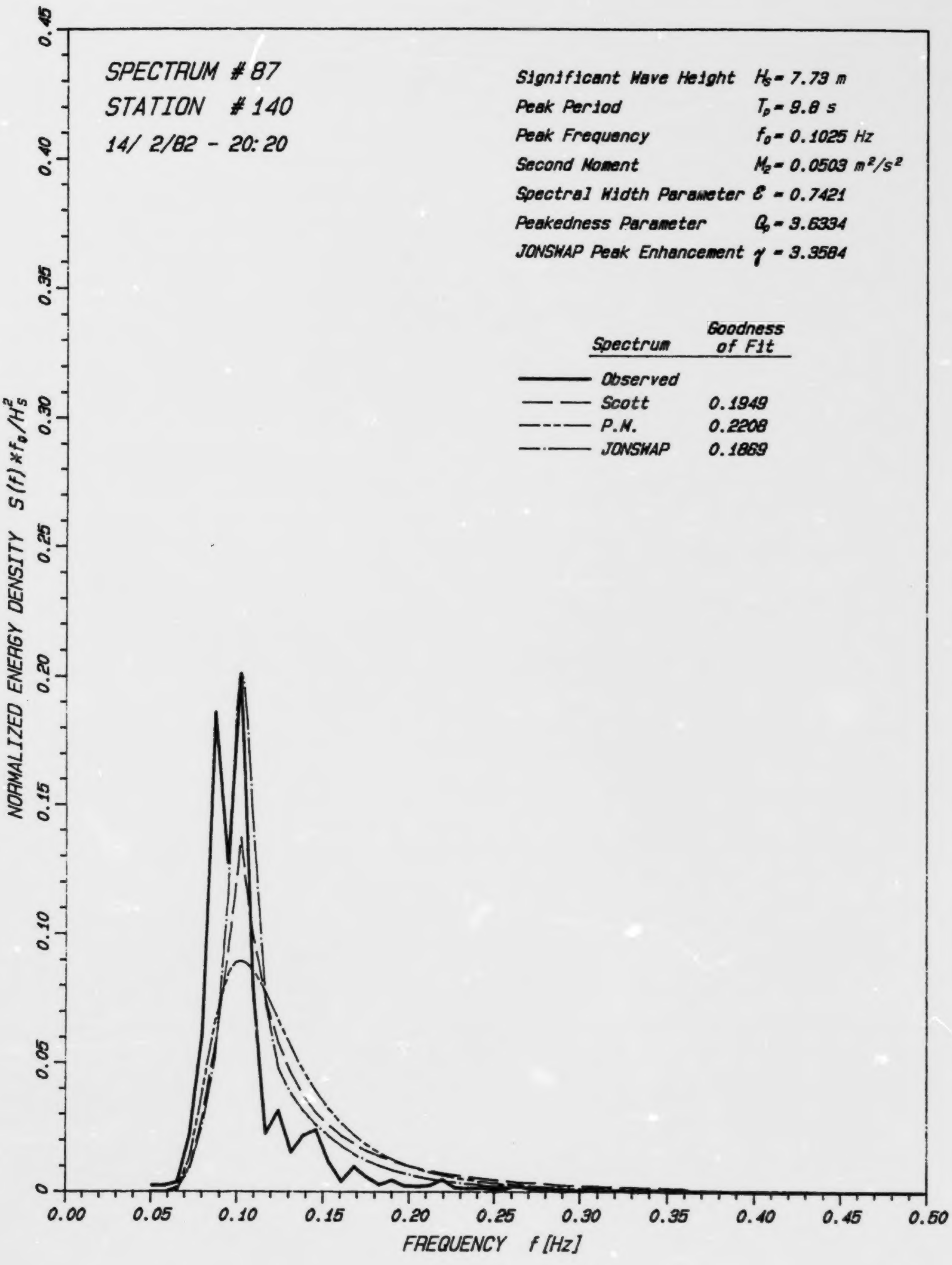
SPECTRUM # 82
STATION # 140
14/ 2/82 - 18: 40
Significant Wave Height H_s = 8.02 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0404 m²/s²
Spectral Width Parameter ε = 0.7419
Peakedness Parameter Q_p = 2.9987
JONSWAP Peak Enhancement γ = 3.3181
Spectrum
Goodness of Fit
Observed
Scott 0.1175
P.M. 0.1654
JONSWAP 0.0789
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

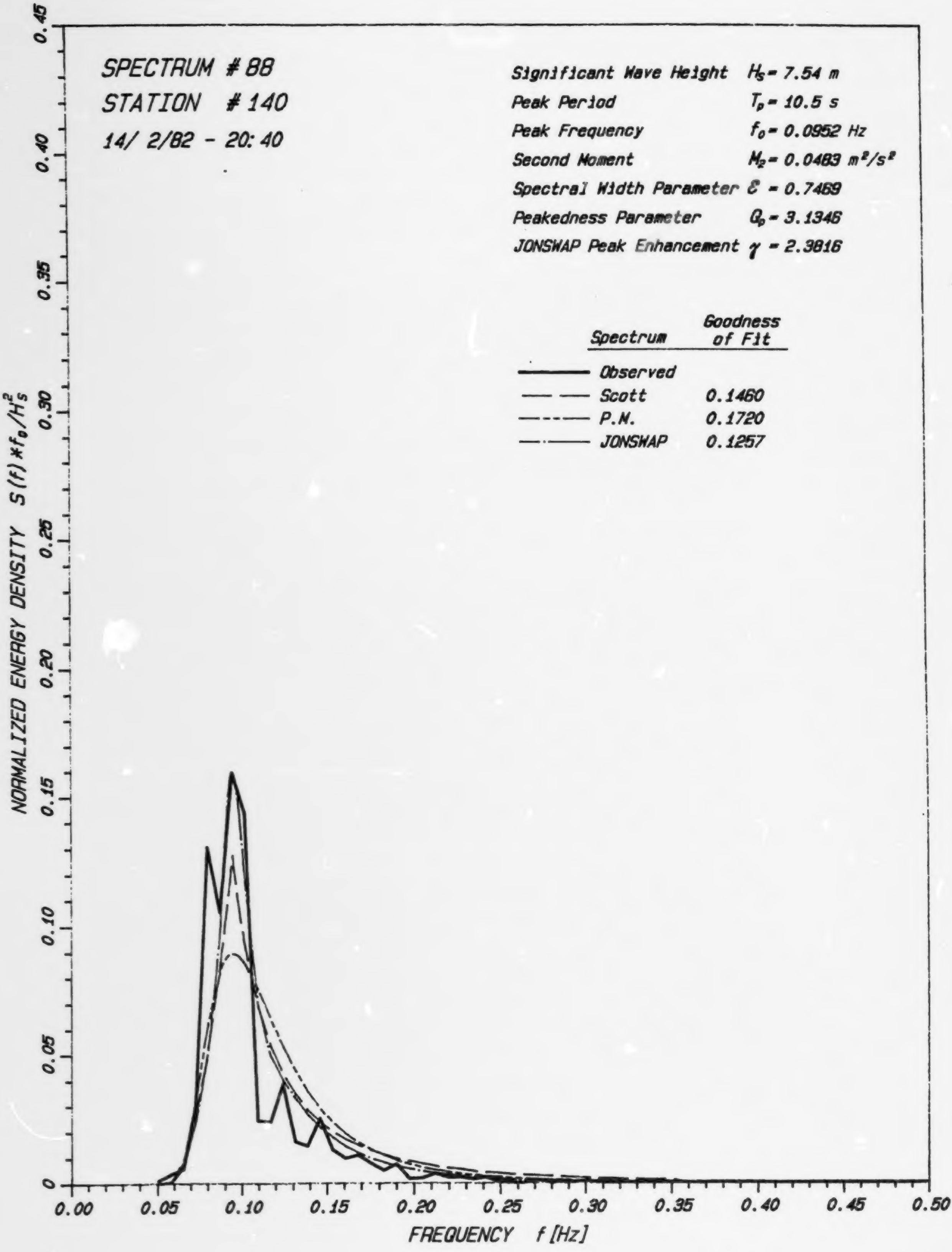

SPECTRUM # 83
STATION # 140
14/ 2/82 - 19:00
Significant Wave Height H_s = 6.00 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0381 m^2/s^2
Spectral Width Parameter ε = 0.7387
Peakedness Parameter Q_p = 2.6731
JONSWAP Peak Enhancement γ = 1.6655
Spectrum
Goodness of Fit
Observed
Scott 0.1336
P.M. 0.1394
JONSWAP 0.1348
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

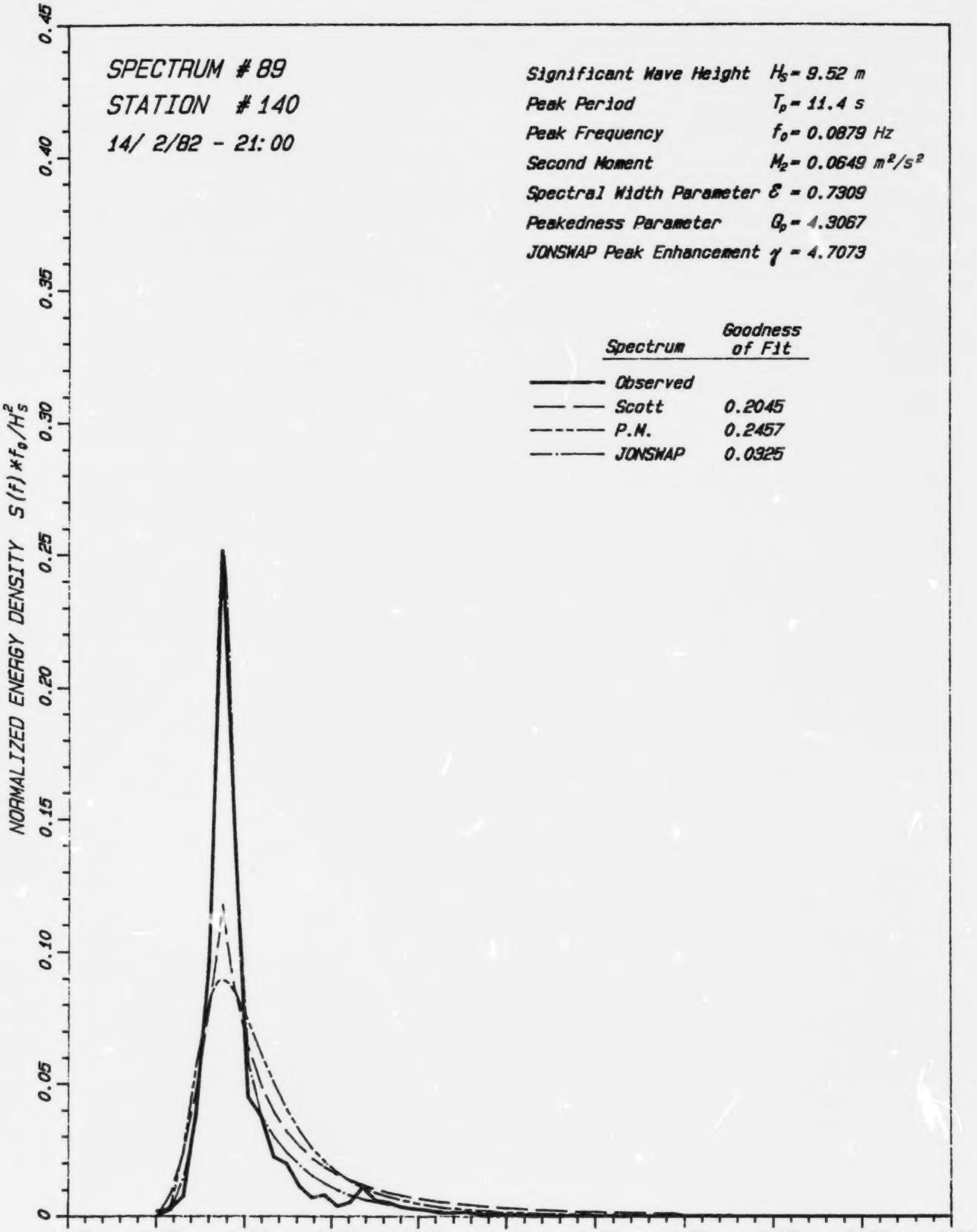

SPECTRUM # 84
STATION # 140
14/ 2/82 - 19: 20
Significant Wave Height H_s = 6.49 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0437 m^2/s^2
Spectral Width Parameter ε = 0.7360
Peakedness Parameter Q_p = 2.6810
JONSWAP Peak Enhancement γ = 1.8811
Spectrum
Goodness of Fit
Observed
Scott 0.0874
P.M. 0.1126
JONSWAP 0.0774
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

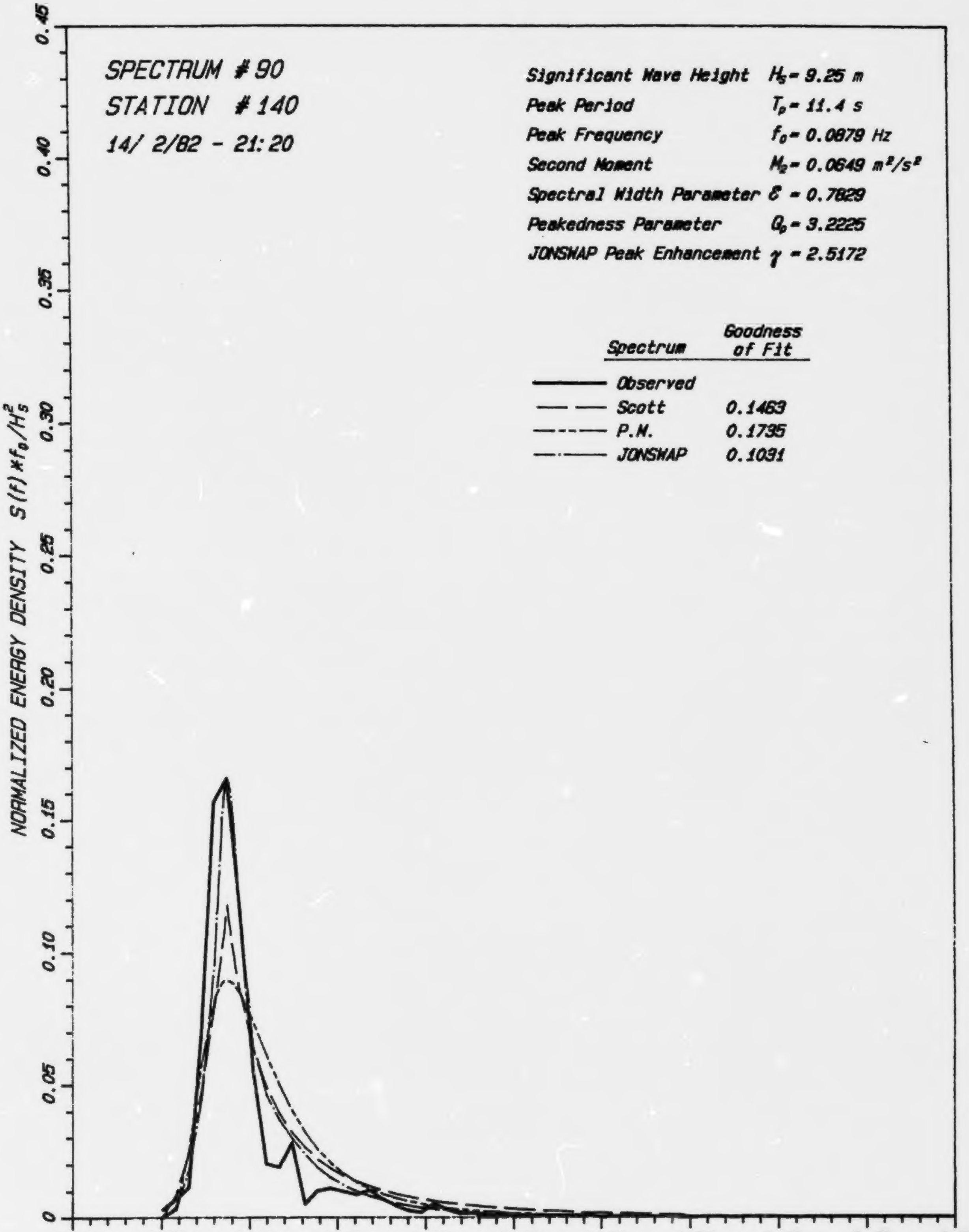

SPECTRUM # 85
STATION # 140
14/ 2/82 - 19: 40
Significant Wave Height H_s = 6.79 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0474 m^2/s^2
Spectral Width Parameter ε = 0.7277
Peakedness Parameter Q_p = 2.8976
JONSWAP Peak Enhancement γ = 2.0332
Spectrum
Goodness of Fit
Observed
Scott 0.0954
P.M. 0.1228
JONSWAP 0.0834
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

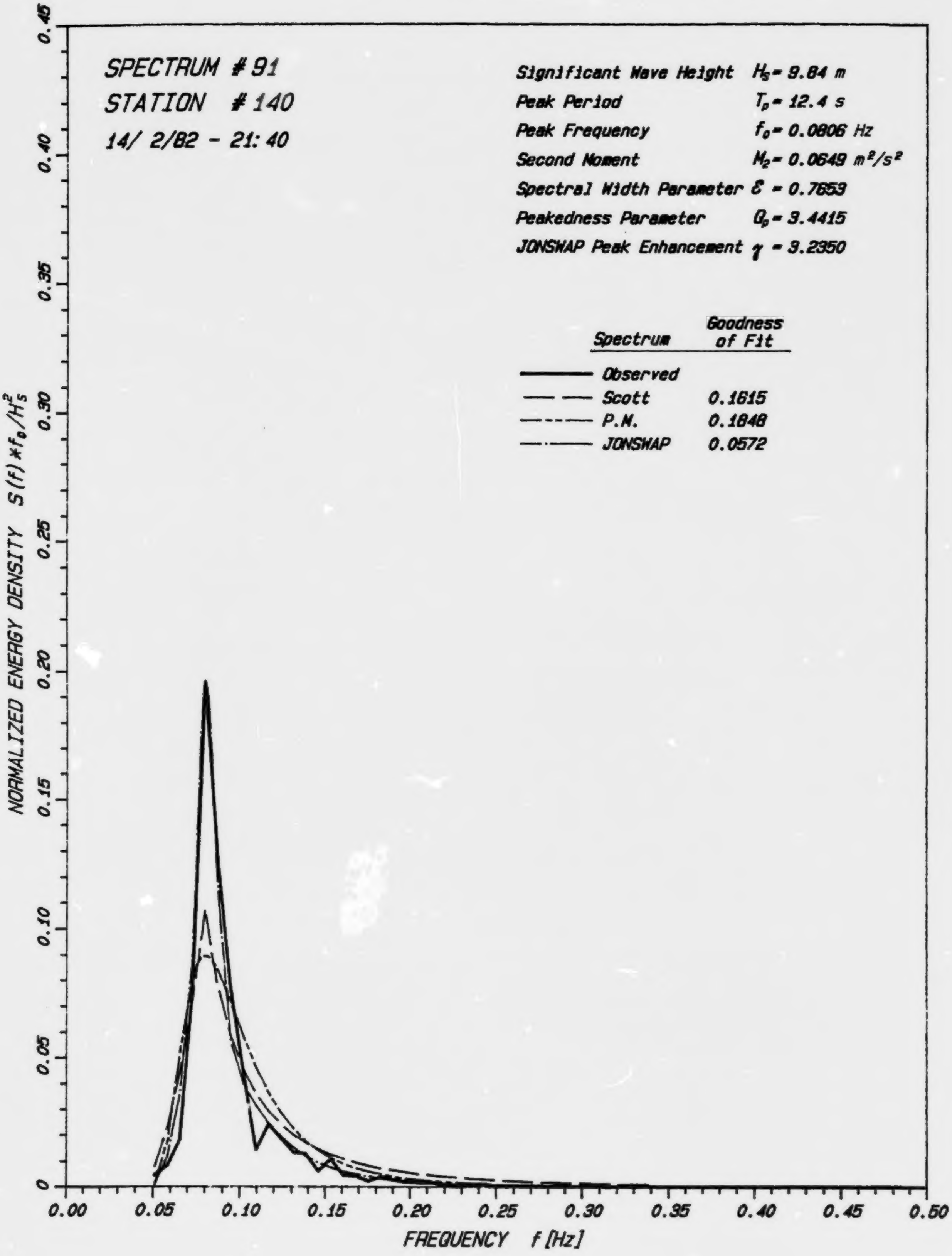

SPECTRUM # 86
STATION # 140
14/ 2/82 - 20: 00
Significant Wave Height H_s = 7.14 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0491 m^2/s^2
Spectral Width Parameter ε = 0.7200
Peakedness Parameter Q_p = 3.5950
JONSWAP Peak Enhancement γ = 3.7368
Spectrum
Goodness of Fit
Observed
Scott 0.1703
P.M. 0.2079
JONSWAP 0.1525
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

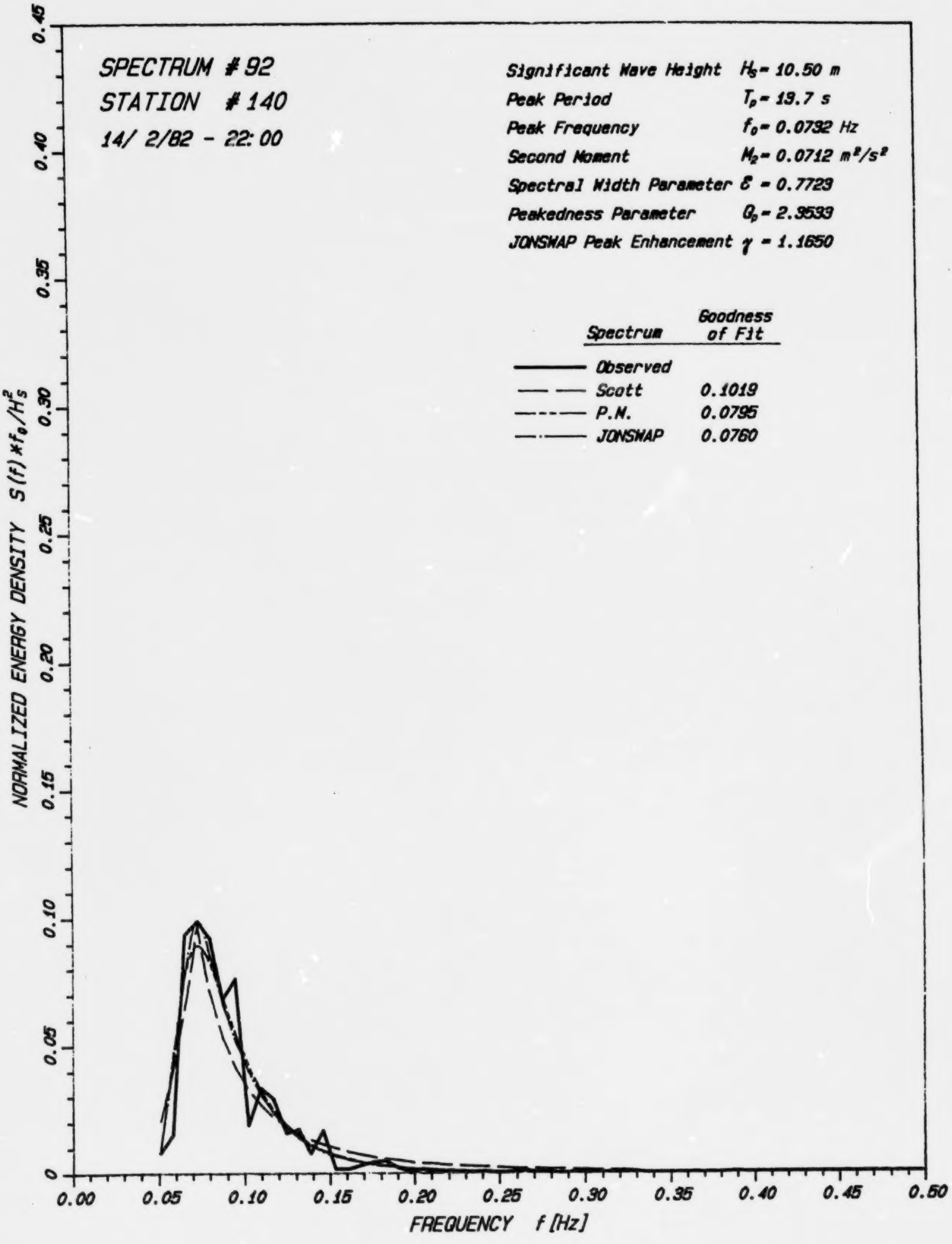

SPECTRUM # 87
STATION # 140
14/ 2/82 - 20:20
Significant Wave Height H_s = 7.73 m
Peak Period T_p = 9.8 s
Peak Frequency f_0 = 0.1025 Hz
Second Moment M_2 = 0.0503 m²/s²
Spectral Width Parameter $\mathcal{E}$ = 0.7421
Peakedness Parameter Q_p = 3.6334
JONSWAP Peak Enhancement γ = 3.3584
Spectrum
Goodness of Fit
Observed
Scott 0.1949
P.M. 0.2208
JONSWAP 0.1869
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

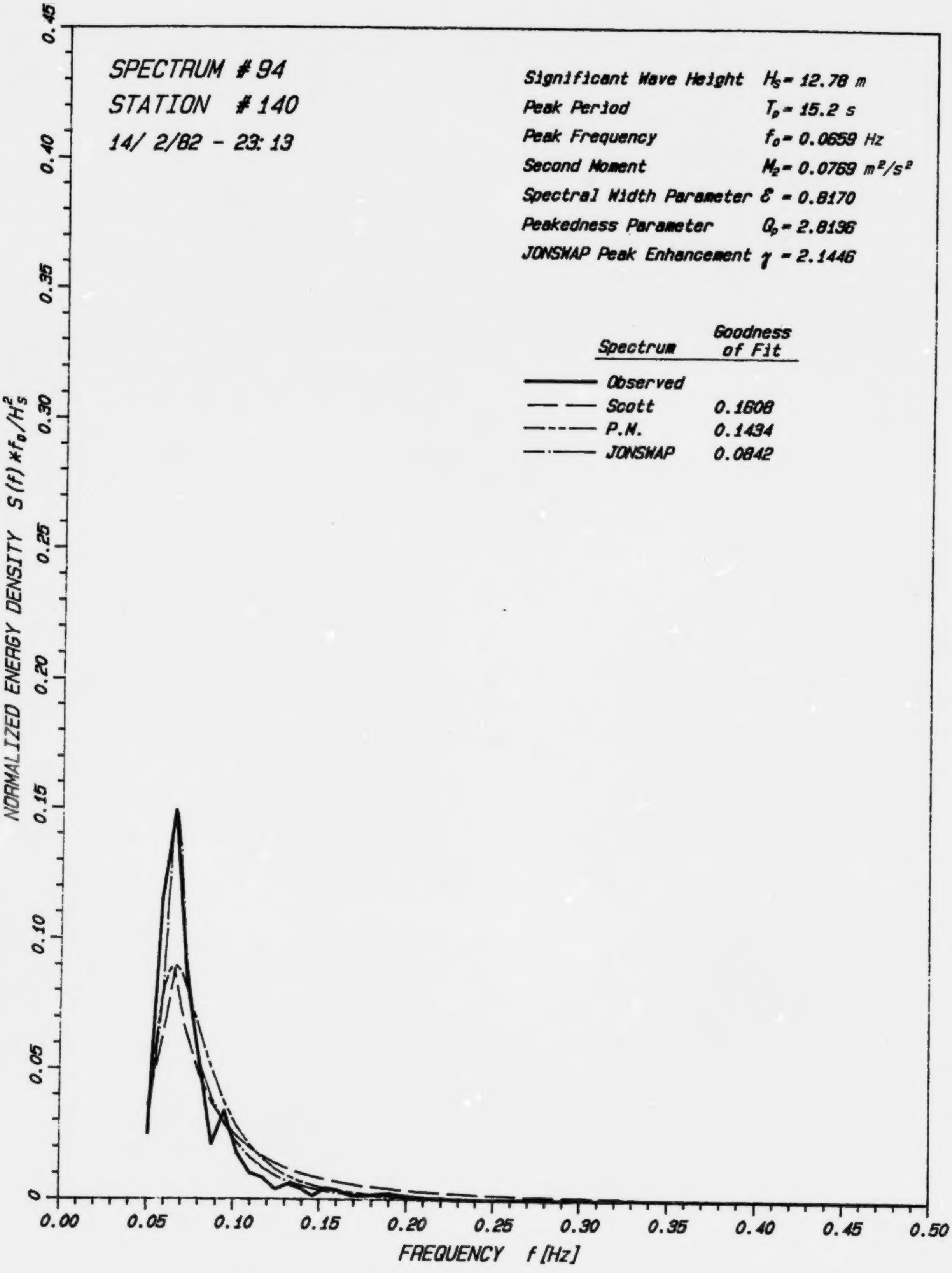

SPECTRUM # 88
STATION # 140
14/ 2/82 - 20: 40
Significant Wave Height H_s = 7.54 m
Peak Period T_p = 10.5 s
Peak Frequency f_0 = 0.0952 Hz
Second Moment M_2 = 0.0483 m^2/s^2
Spectral Width Parameter ε = 0.7469
Peakedness Parameter Q_p = 3.1346
JONSWAP Peak Enhancement γ = 2.3816
Spectrum
Goodness of Fit
Observed
Scott 0.1460
P.M. 0.1720
JONSWAP 0.1257
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

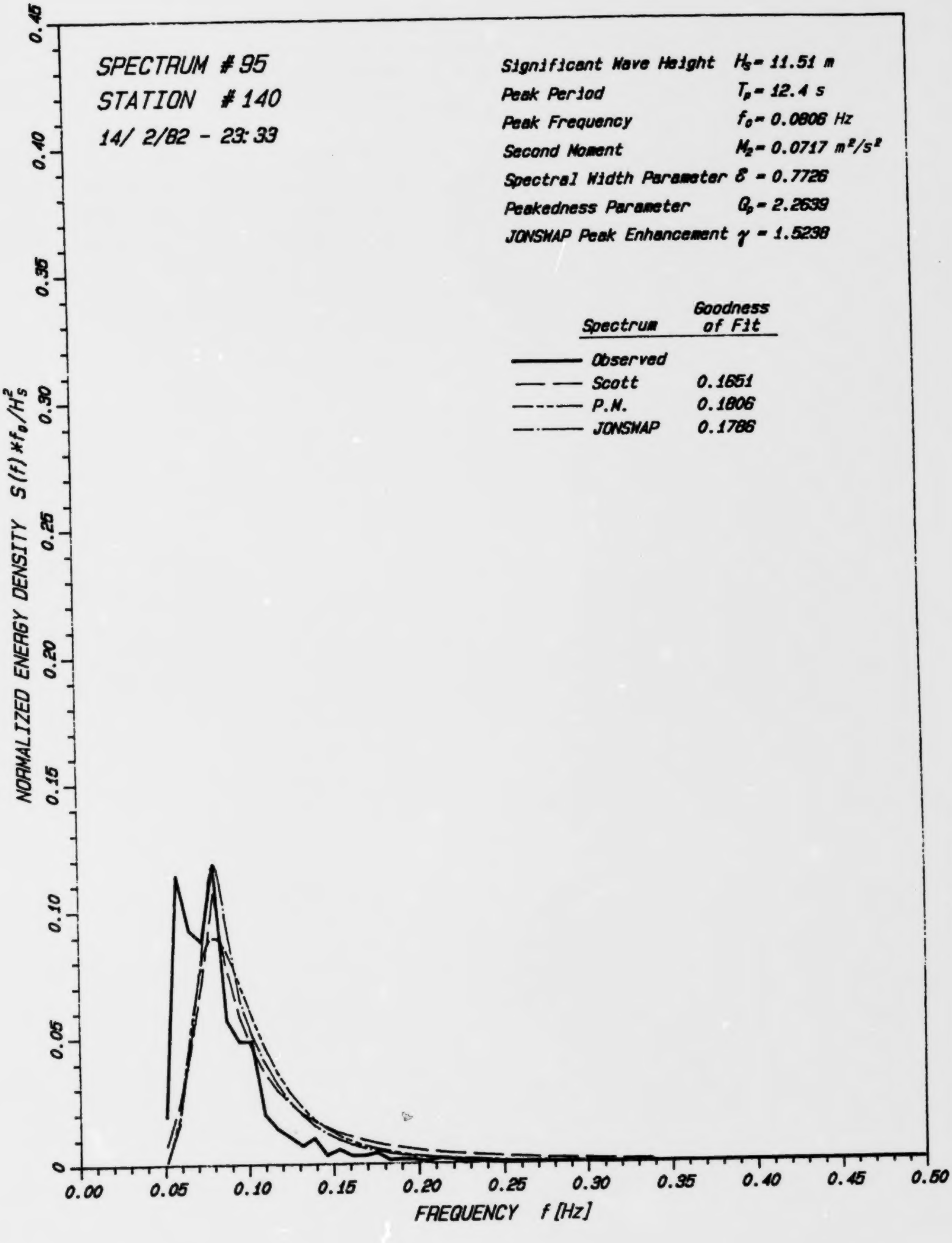

SPECTRUM # 89
STATION # 140
14/ 2/82 - 21:00
Significant Wave Height H_s = 9.52 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0649 m^2/s^2
Spectral Width Parameter ε = 0.7309
Peakedness Parameter Q_p = 4.3067
JONSWAP Peak Enhancement γ = 4.7073
Spectrum
Goodness of Fit
Observed
Scott 0.2045
P.M. 0.2457
JONSWAP 0.0325
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

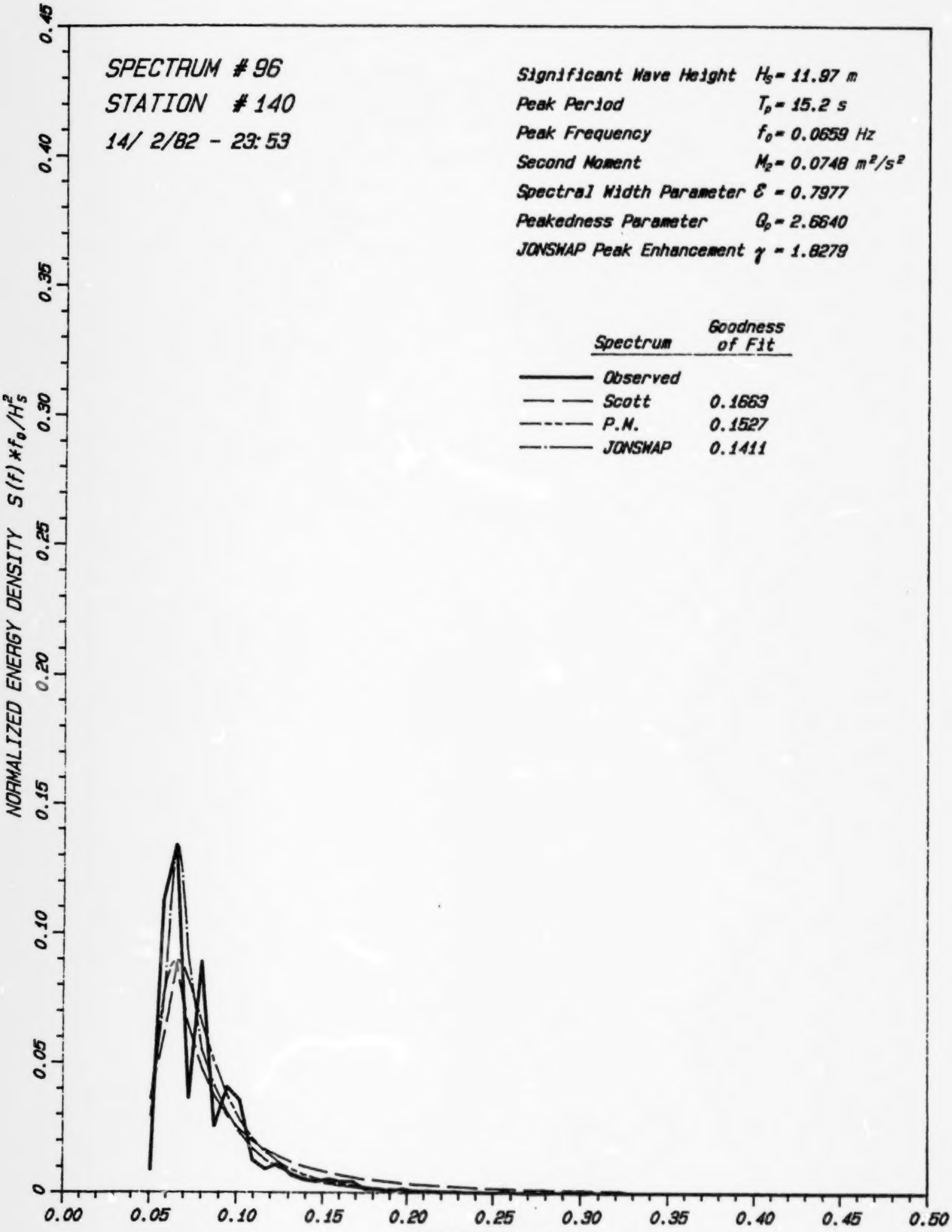

SPECTRUM # 90
STATION # 140
14/ 2/82 - 21:20
Significant Wave Height H_s = 9.25 m
Peak Period T_p = 11.4 s
Peak Frequency f_0 = 0.0879 Hz
Second Moment M_2 = 0.0649 m^2/s^2
Spectral Width Parameter ε = 0.7829
Peakedness Parameter Q_p = 3.2225
JONSWAP Peak Enhancement γ = 2.5172
Spectrum
Goodness of Fit
Observed
Scott 0.1463
P.M. 0.1735
JONSWAP 0.1031
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

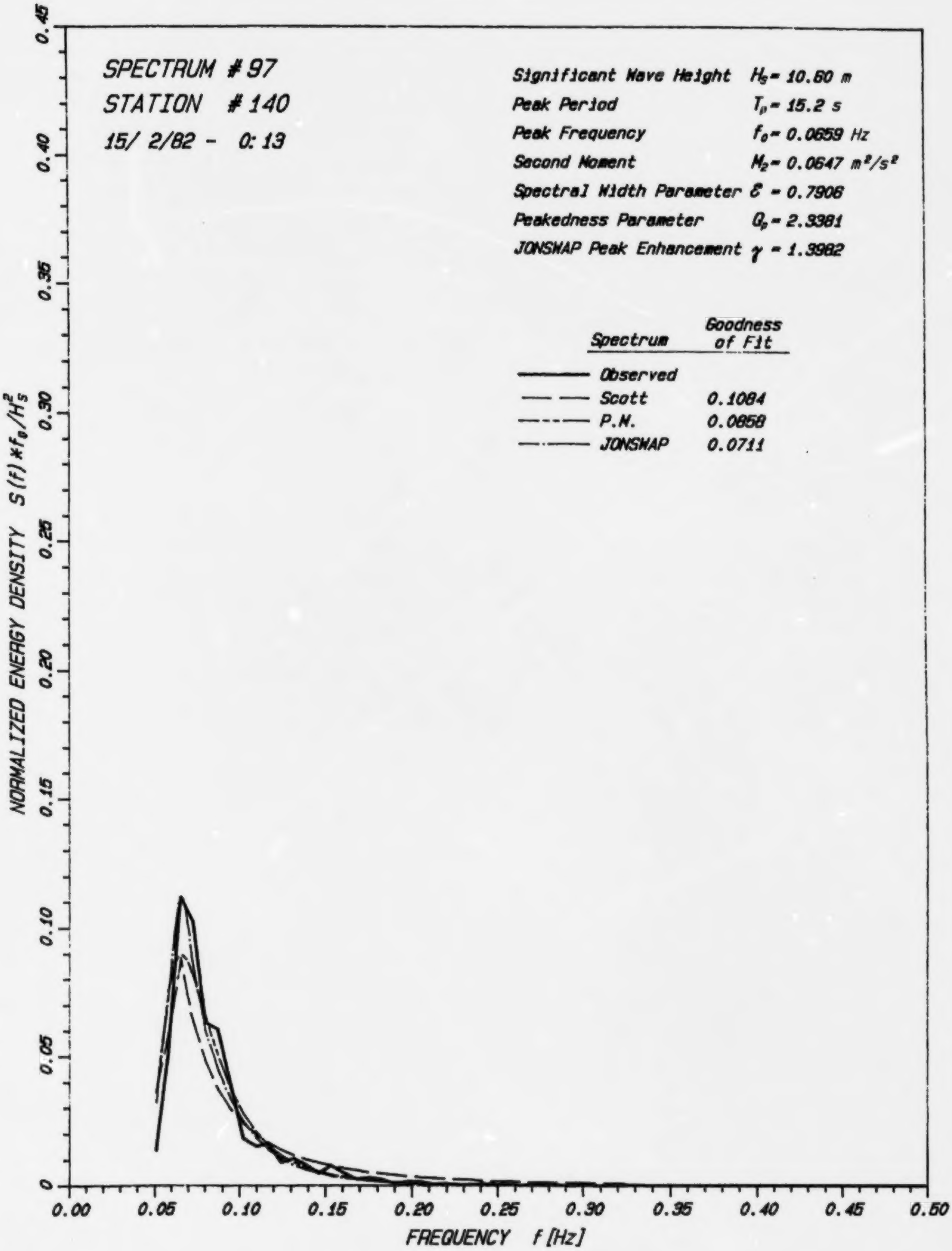

SPECTRUM # 91
STATION # 140
14/ 2/82 - 21: 40
Significant Wave Height H_s = 9.84 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0649 m²/s²
Spectral Width Parameter ε = 0.7653
Peakedness Parameter Q_p = 3.4415
JONSWAP Peak Enhancement γ = 3.2350
Spectrum
Goodness of Fit
Observed
Scott 0.1615
P.M. 0.1848
JONSWAP 0.0572
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

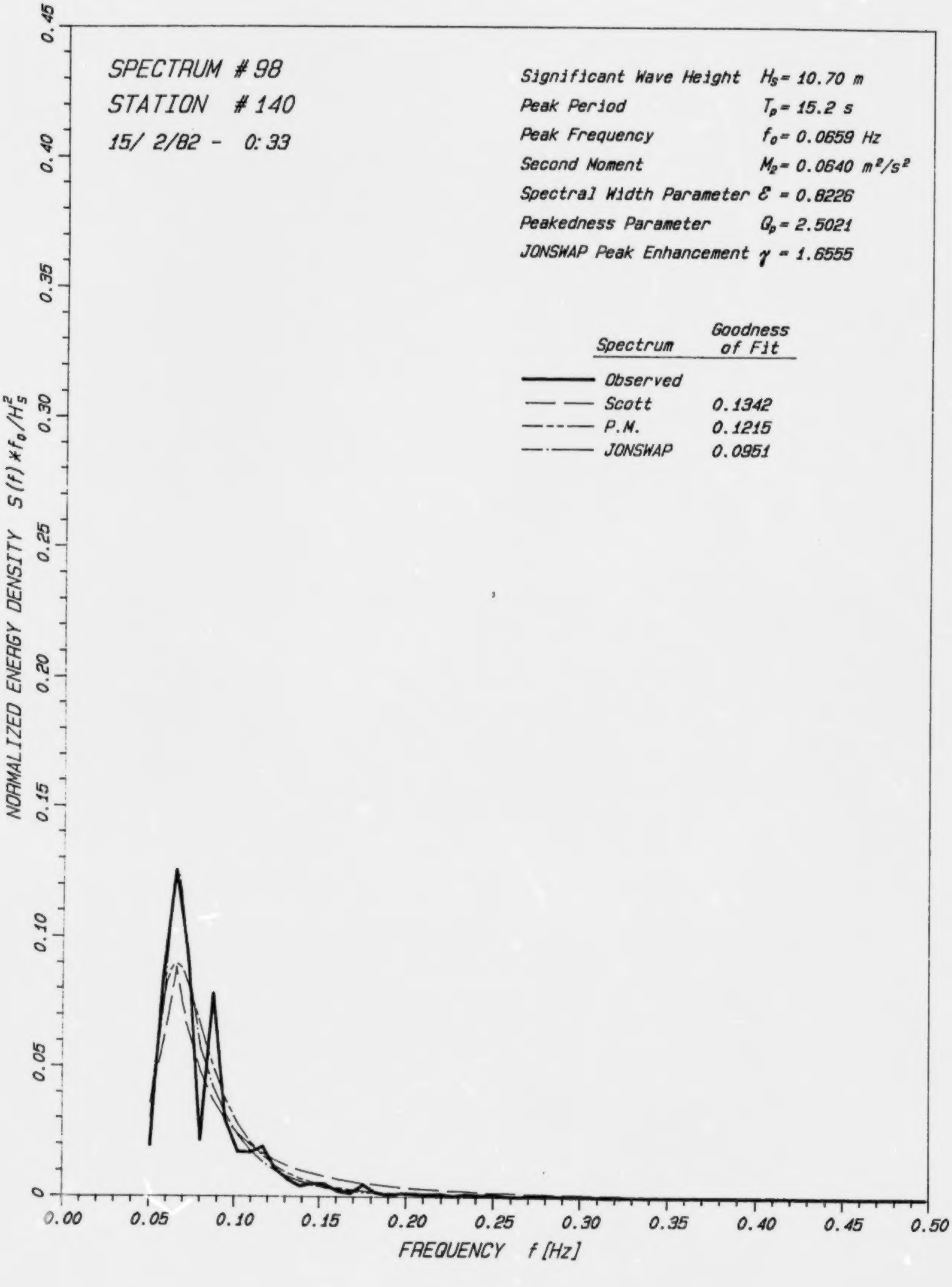

SPECTRUM # 92
STATION # 140
14/ 2/82 - 22: 00
Significant Wave Height H_s = 10.50 m
Peak Period T_p = 13.7 s
Peak Frequency f_0 = 0.0732 Hz
Second Moment M_2 = 0.0712 m^2/s^2
Spectral Width Parameter ε = 0.7723
Peakedness Parameter Q_p = 2.3533
JONSWAP Peak Enhancement γ = 1.1650
Spectrum
Goodness of Fit
Observed
Scott 0.1019
P.M. 0.0795
JONSWAP 0.0760
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

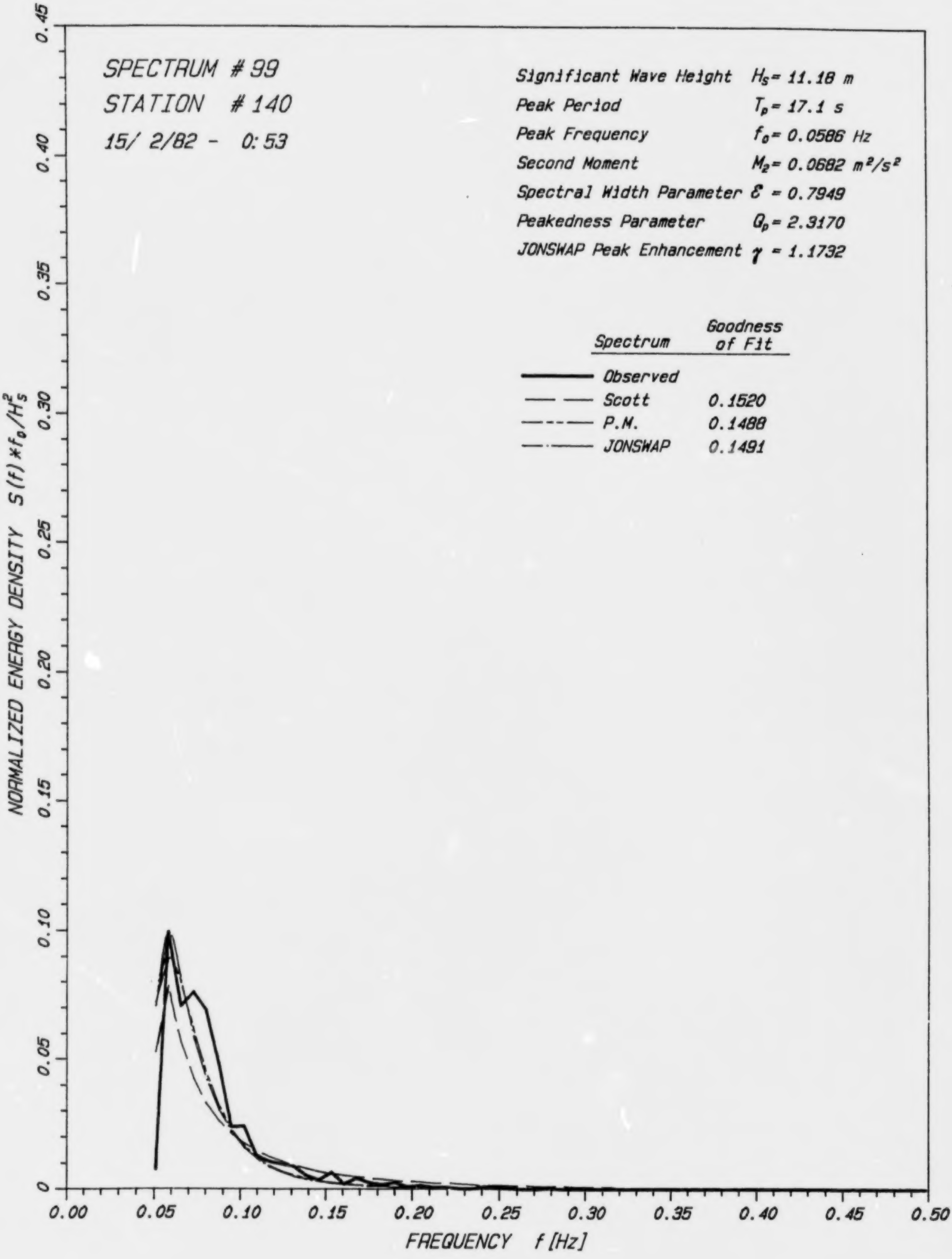

SPECTRUM # 94
STATION # 140
14/ 2/82 - 23: 13
Significant Wave Height H_s = 12.78 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0769 m^2/s^2
Spectral Width Parameter ε = 0.8170
Peakedness Parameter Q_p = 2.8136
JONSWAP Peak Enhancement γ = 2.1446
Spectrum
Goodness of Fit
Observed
Scott 0.1608
P.M. 0.1434
JONSWAP 0.0842
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

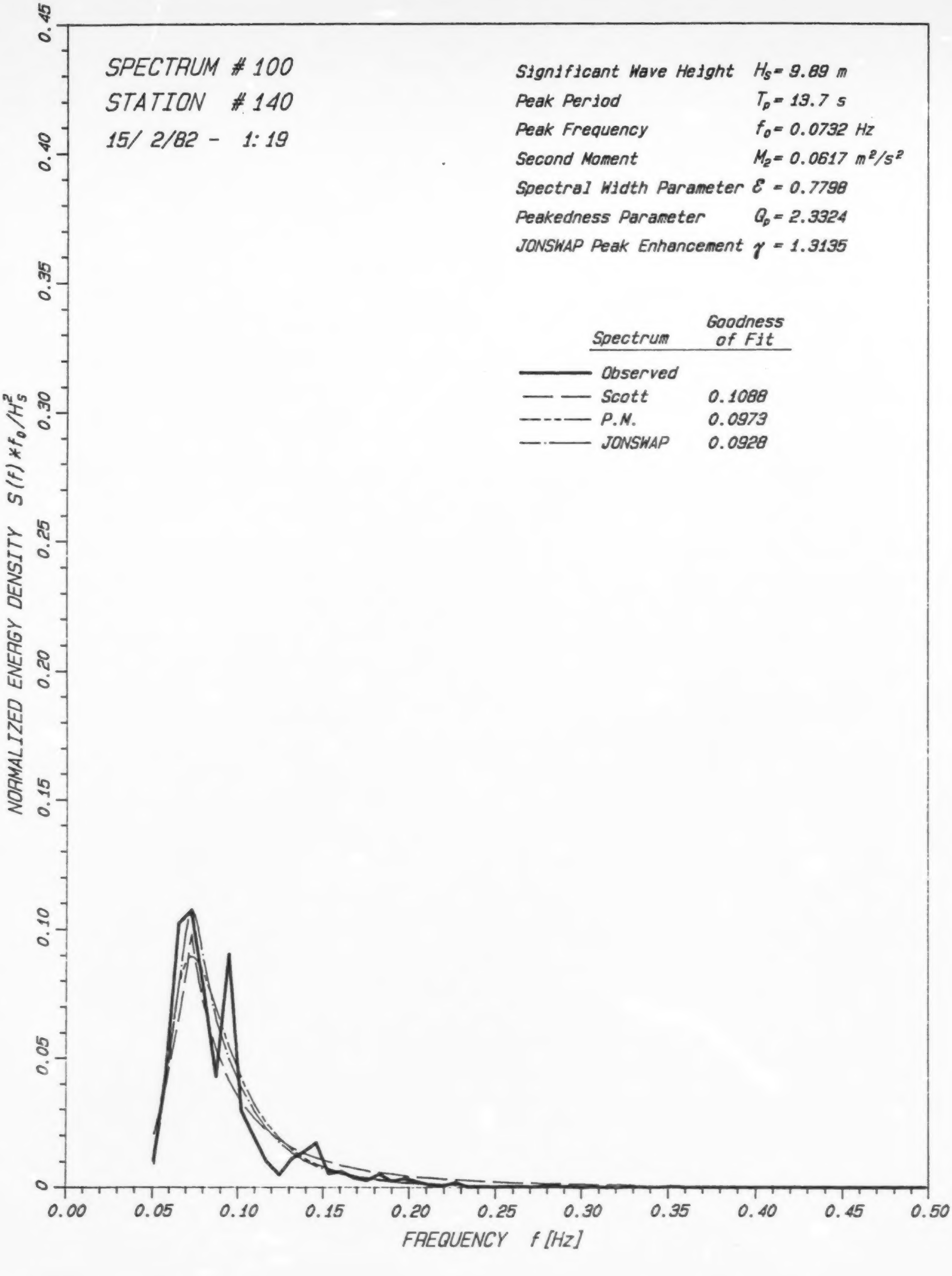

SPECTRUM # 95
STATION # 140
14/ 2/82 - 23:33
Significant Wave Height H_s = 11.51 m
Peak Period T_p = 12.4 s
Peak Frequency f_0 = 0.0806 Hz
Second Moment M_2 = 0.0717 m²/s²
Spectral Width Parameter ε = 0.7726
Peakedness Parameter Q_p = 2.2639
JONSWAP Peak Enhancement γ = 1.5238
Spectrum
Goodness of Fit
Observed
Scott 0.1651
P.M. 0.1806
JONSWAP 0.1786
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

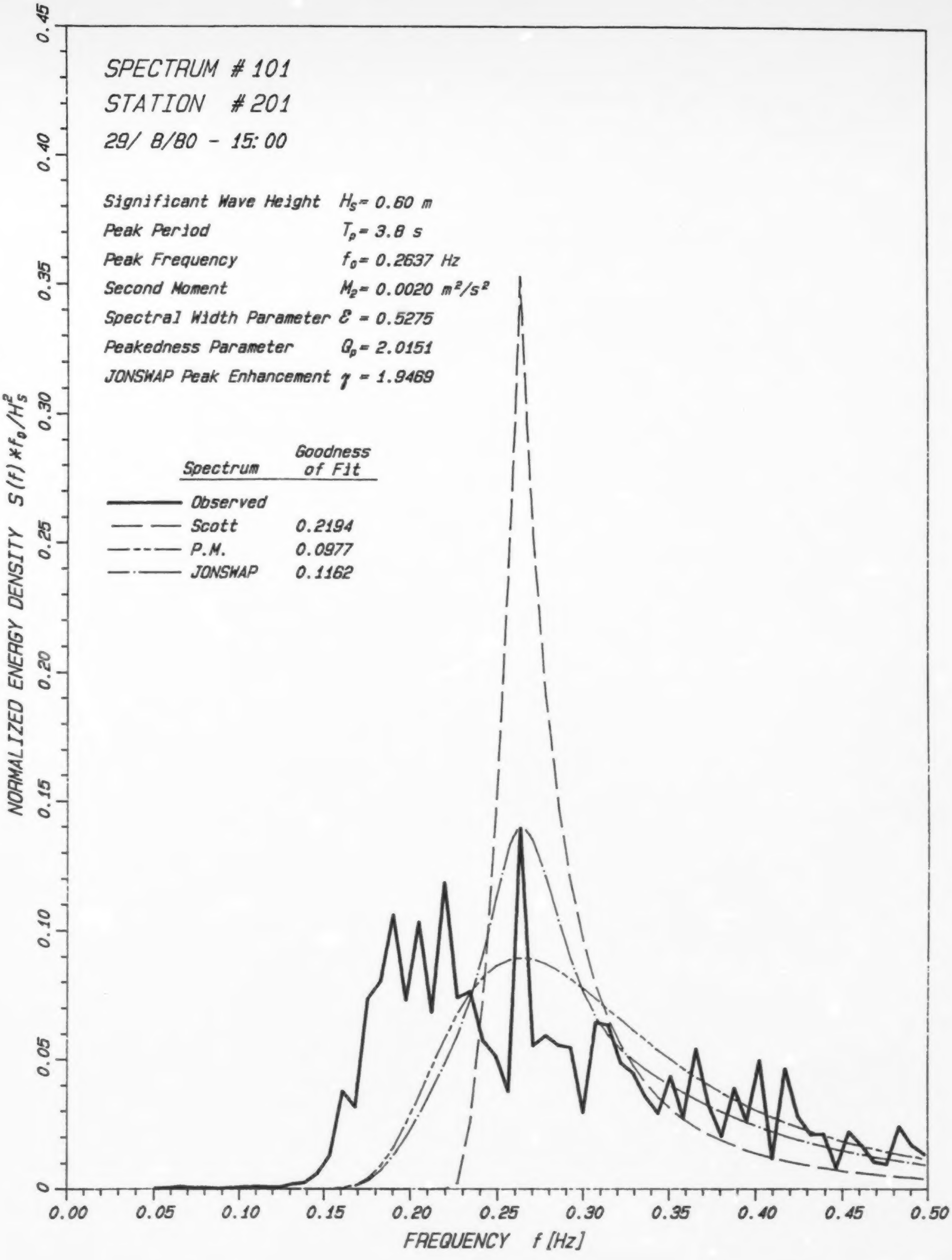

SPECTRUM # 96
STATION # 140
14/ 2/82 - 23:53
Significant Wave Height H_s = 11.97 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0748 m^2/s^2
Spectral Width Parameter ε = 0.7977
Peakedness Parameter Q_p = 2.6640
JONSWAP Peak Enhancement γ = 1.8279
Spectrum
Goodness of Fit
Observed
Scott 0.1663
P.M. 0.1527
JONSWAP 0.1411
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

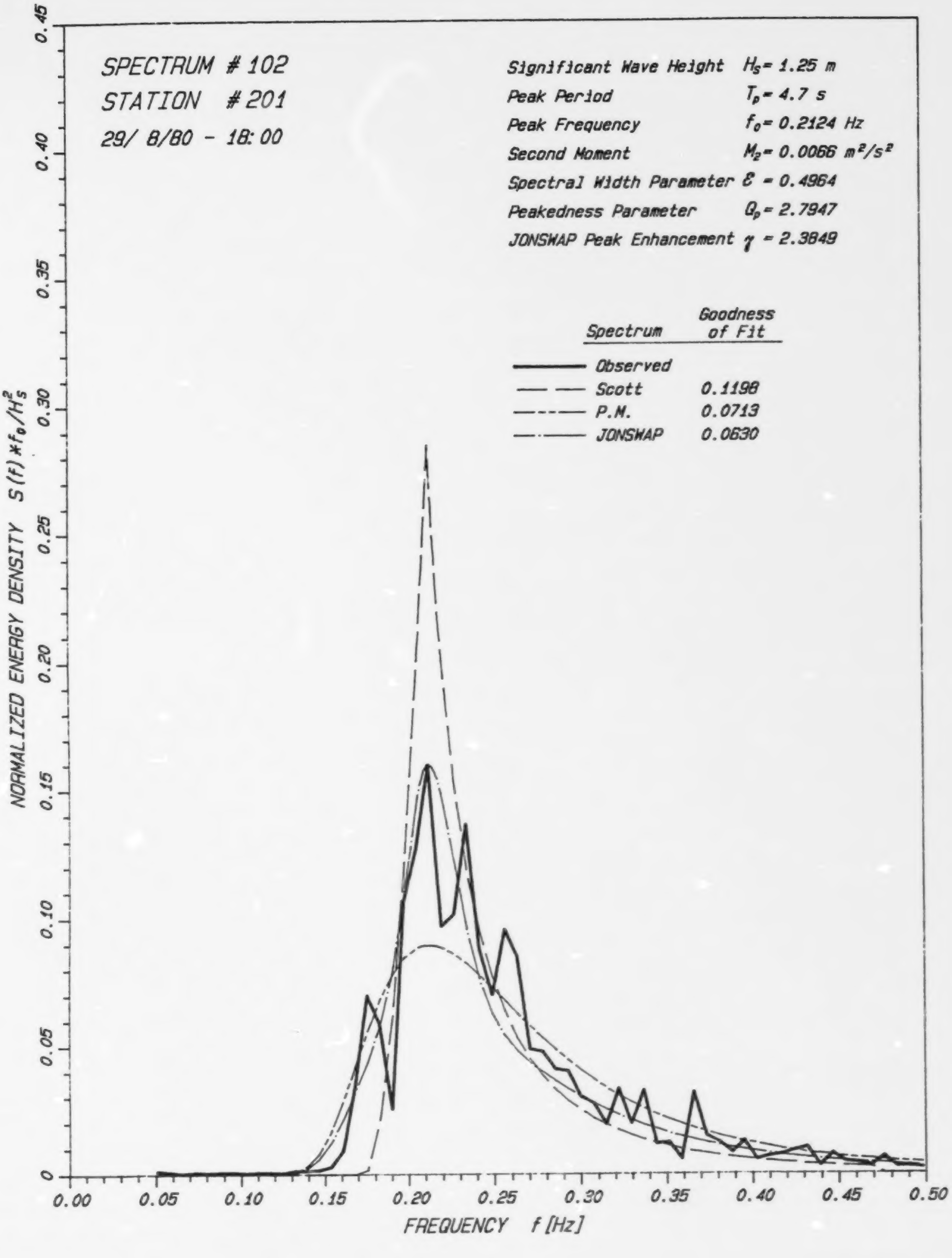

SPECTRUM # 97
STATION # 140
15/ 2/82 - 0: 13
Significant Wave Height H_s = 10.60 m
Peak Period T_p = 15.2 s
Peak Frequency f_0 = 0.0659 Hz
Second Moment M_2 = 0.0647 m²/s²
Spectral Width Parameter ε = 0.7906
Peakedness Parameter Q_p = 2.3381
JONSWAP Peak Enhancement γ = 1.3982
Spectrum
Goodness of Fit
Observed
Scott 0.1084
P.M. 0.0858
JONSWAP 0.0711
NORMALIZED ENERGY DENSITY $S(f) * f_0 / H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

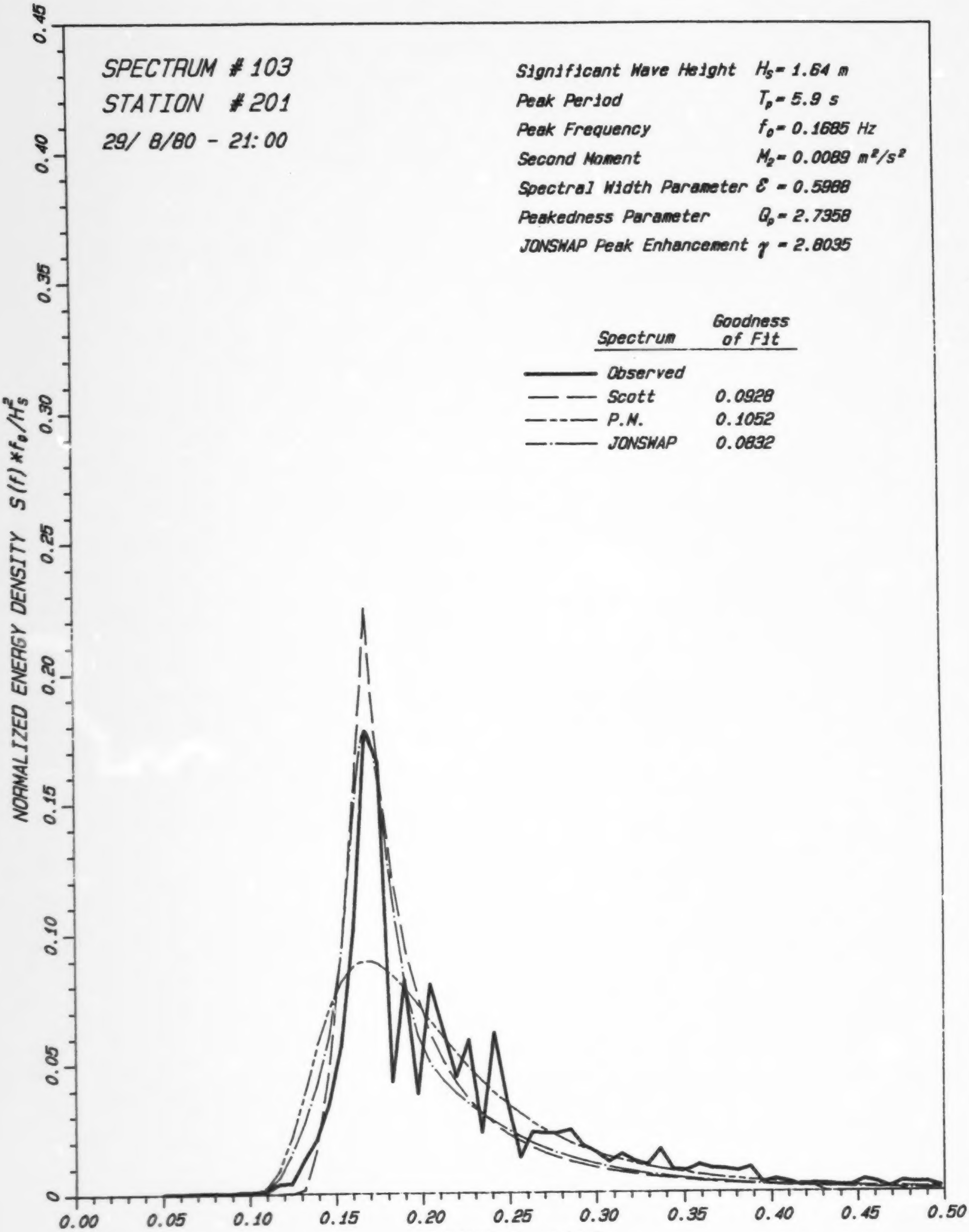

SPECTRUM # 98
STATION # 140
15/ 2/82 - 0: 33
Significant Wave Height H_s= 10.70 m
Peak Period T_p= 15.2 s
Peak Frequency f_0= 0.0659 Hz
Second Moment M_2= 0.0640 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.8226
Peakedness Parameter Q_p= 2.5021
JONSWAP Peak Enhancement γ = 1.6555
Spectrum
Goodness of Fit
Observed
Scott 0.1342
P.M. 0.1215
JONSWAP 0.0951
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

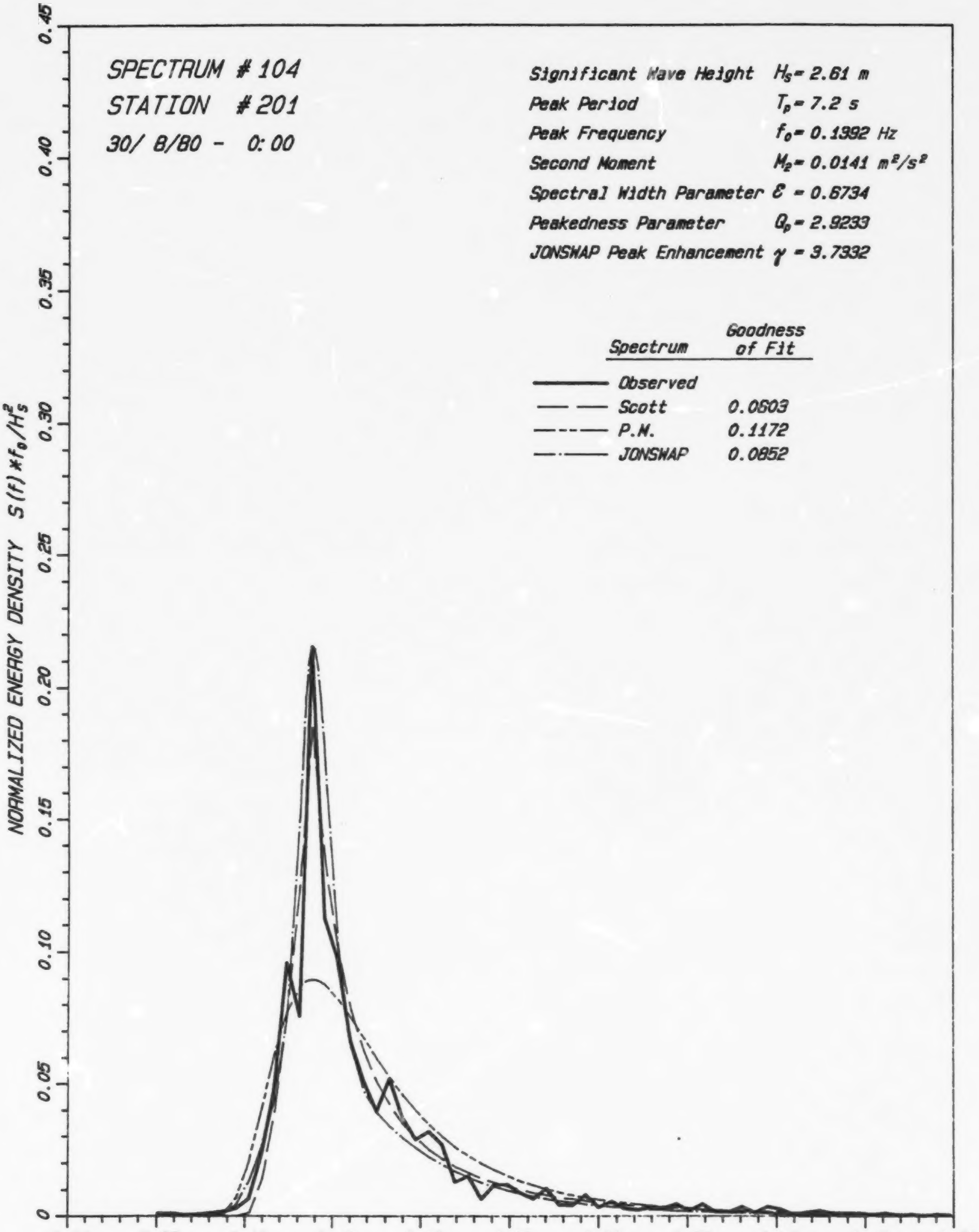

SPECTRUM # 99
STATION # 140
15/ 2/82 - 0: 53
Significant Wave Height H_s = 11.18 m
Peak Period T_p = 17.1 s
Peak Frequency f_0 = 0.0586 Hz
Second Moment M_2 = 0.0682 m^2/s^2
Spectral Width Parameter ε = 0.7949
Peakedness Parameter Q_p = 2.3170
JONSWAP Peak Enhancement γ = 1.1732
Spectrum
Goodness of Fit
Observed
Scott 0.1520
P.M. 0.1488
JONSWAP 0.1491
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

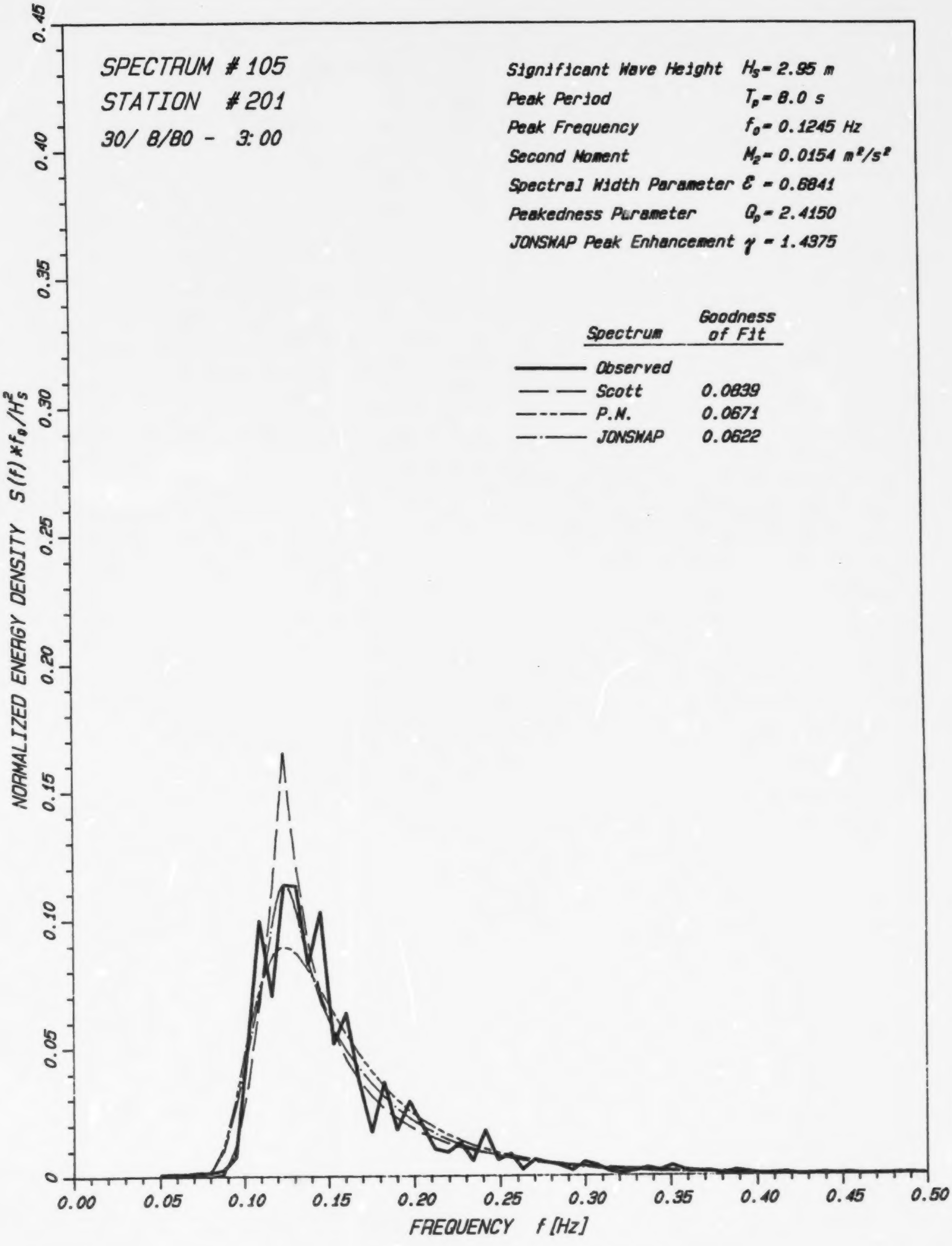

SPECTRUM # 100
STATION # 140
15/ 2/82 - 1: 19
Significant Wave Height H_s = 9.89 m
Peak Period T_p = 13.7 s
Peak Frequency f_0 = 0.0732 Hz
Second Moment M_2 = 0.0617 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.7798
Peakedness Parameter Q_p = 2.3324
JONSWAP Peak Enhancement γ = 1.3135
Spectrum
Goodness of Fit
Observed
Scott 0.1088
P.M. 0.0973
JONSWAP 0.0928
NORMALIZED ENERGY DENSITY $S(f) * f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

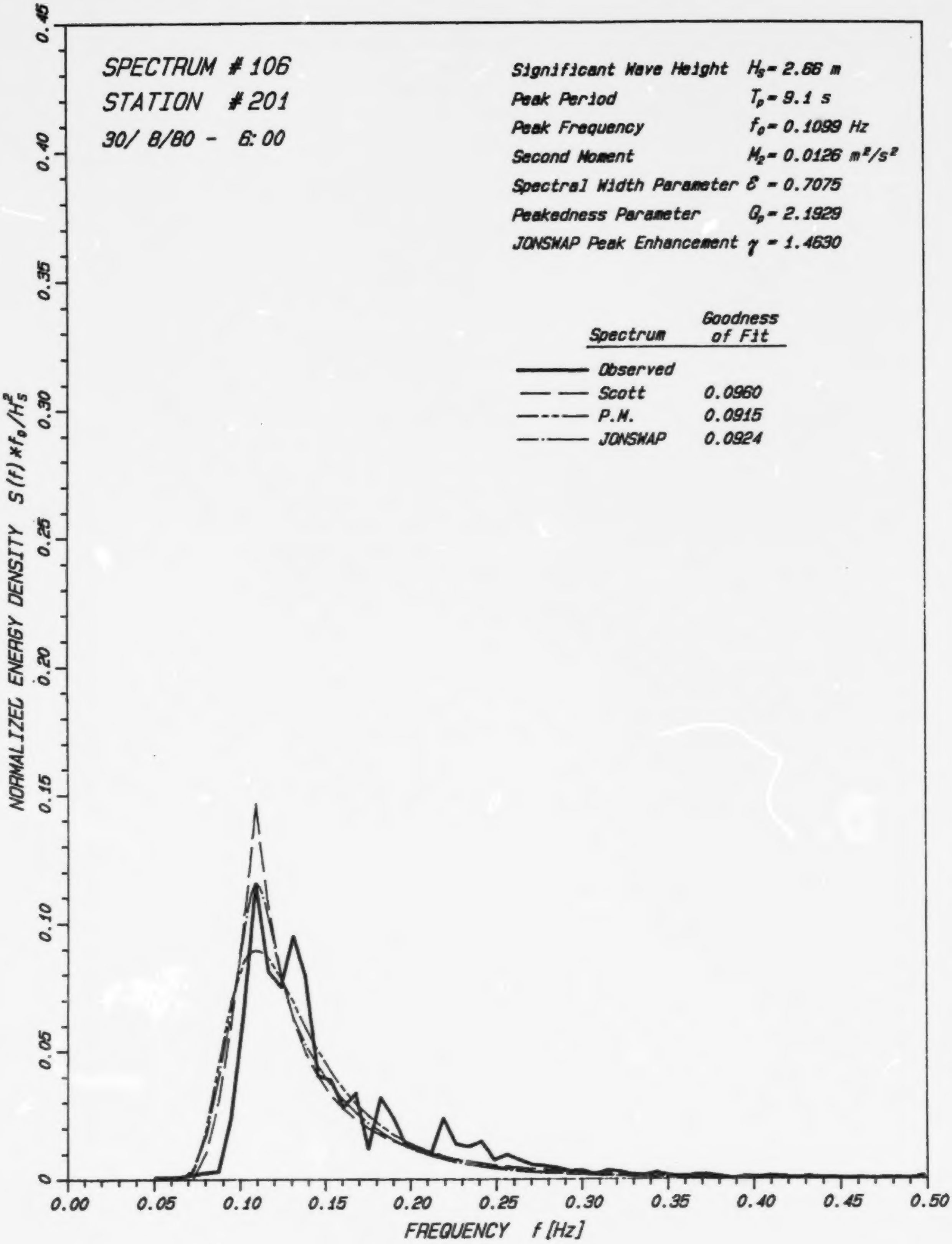

SPECTRUM # 101
STATION # 201
29/ 8/80 - 15:00
Significant Wave Height H_s= 0.60 m
Peak Period T_p= 3.8 s
Peak Frequency f_0= 0.2637 Hz
Second Moment M_2= 0.0020 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.5275
Peakedness Parameter Q_p= 2.0151
JONSWAP Peak Enhancement γ = 1.9469
Spectrum
Goodness of Fit
Observed
Scott 0.2194
P.M. 0.0977
JONSWAP 0.1162
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

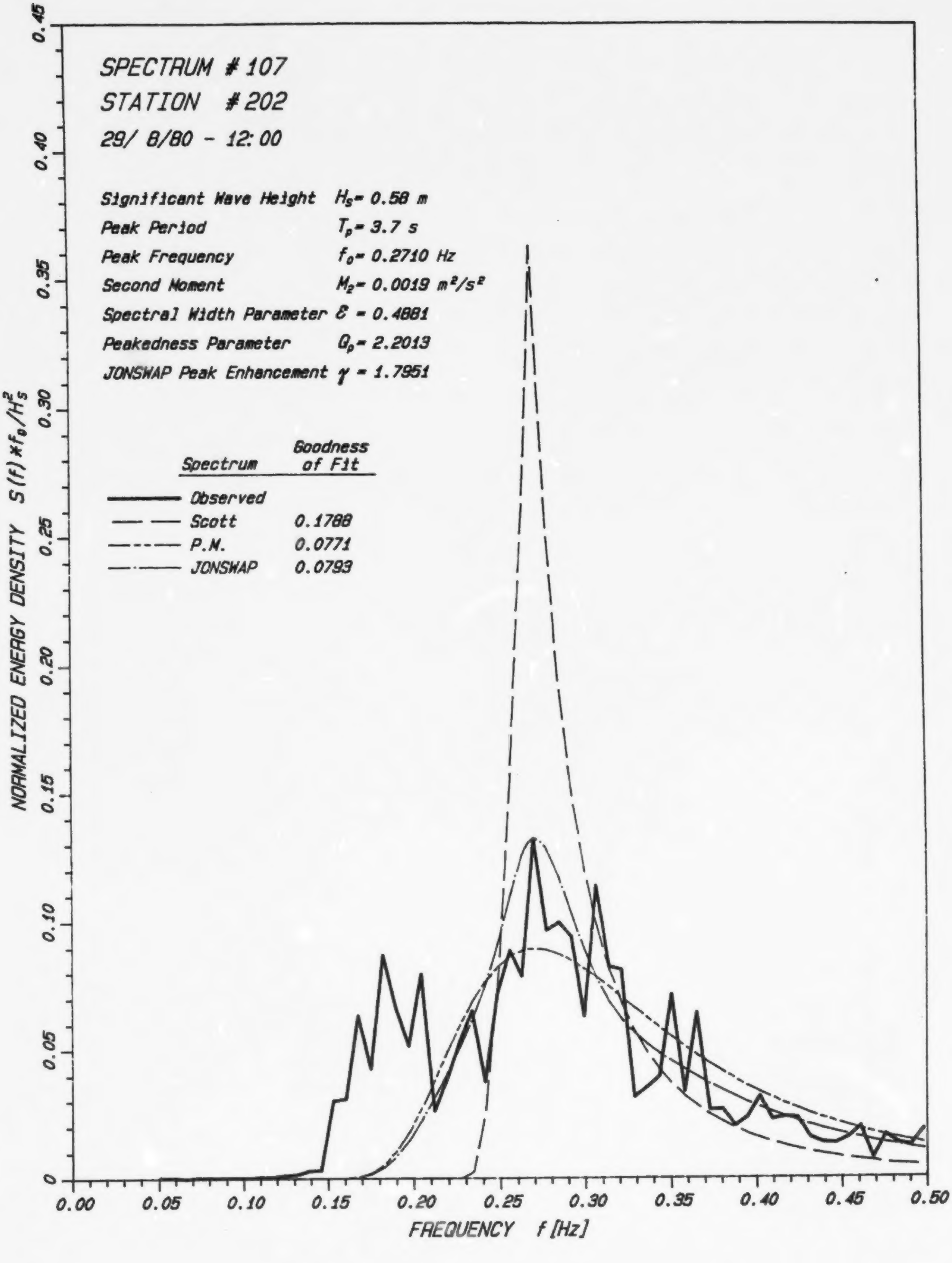

SPECTRUM # 102
STATION # 201
29/ 8/80 - 18:00
Significant Wave Height H_S= 1.25 m
Peak Period T_p= 4.7 s
Peak Frequency f_0= 0.2124 Hz
Second Moment M_2= 0.0066 m^2/s^2
Spectral Width Parameter ε = 0.4964
Peakedness Parameter Q_p= 2.7947
JONSWAP Peak Enhancement γ = 2.3849
Spectrum
Goodness of Fit
Observed
Scott 0.1198
P.M. 0.0713
JONSWAP 0.0630
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

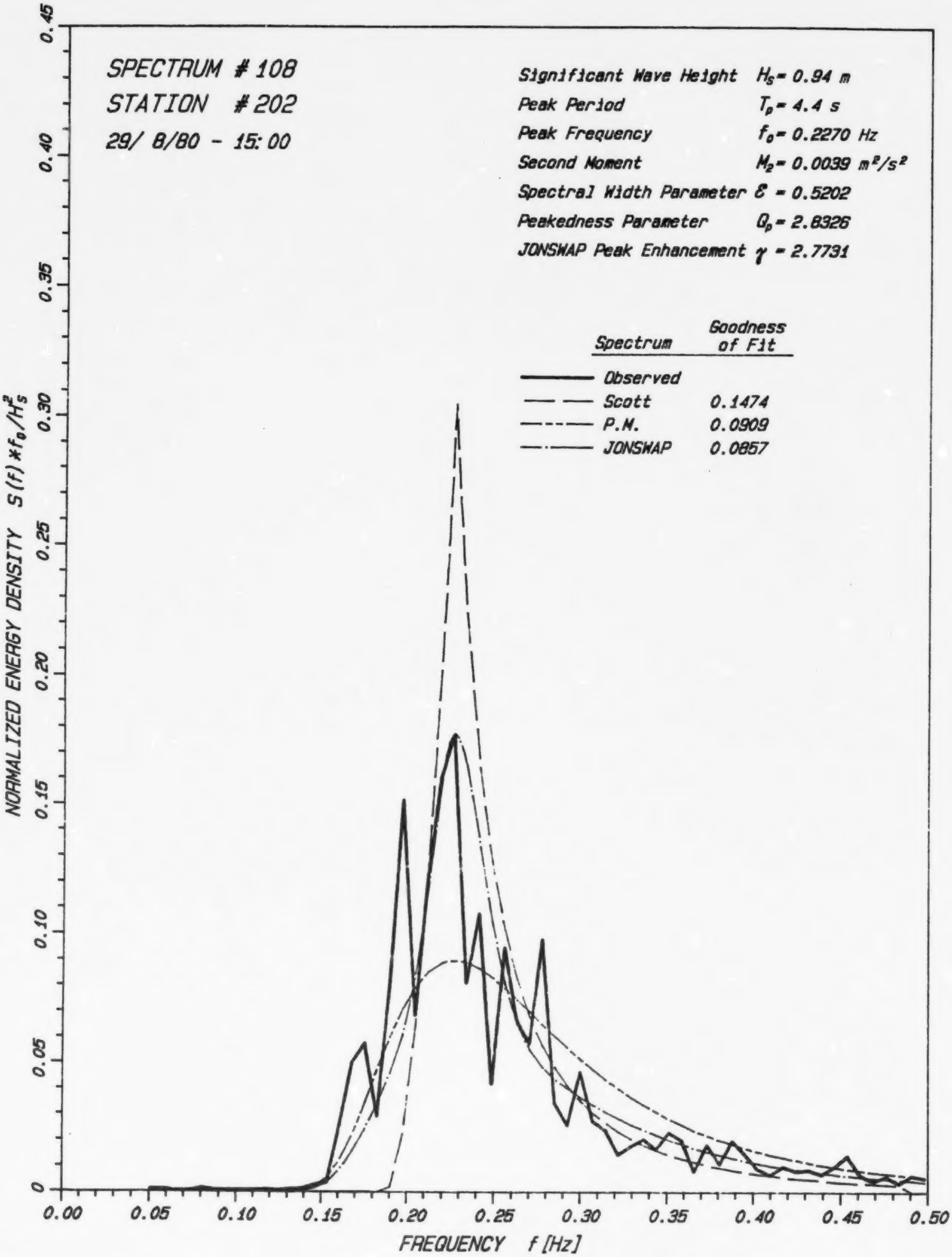

SPECTRUM # 103
STATION # 201
29/ 8/80 - 21:00
Significant Wave Height H_S= 1.64 m
Peak Period T_p= 5.9 s
Peak Frequency f_0= 0.1685 Hz
Second Moment M_2= 0.0089 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.5988
Peakedness Parameter Q_p= 2.7358
JONSWAP Peak Enhancement γ = 2.8035
Spectrum
Goodness of Fit
Observed
Scott 0.0928
P.M. 0.1052
JONSWAP 0.0832
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

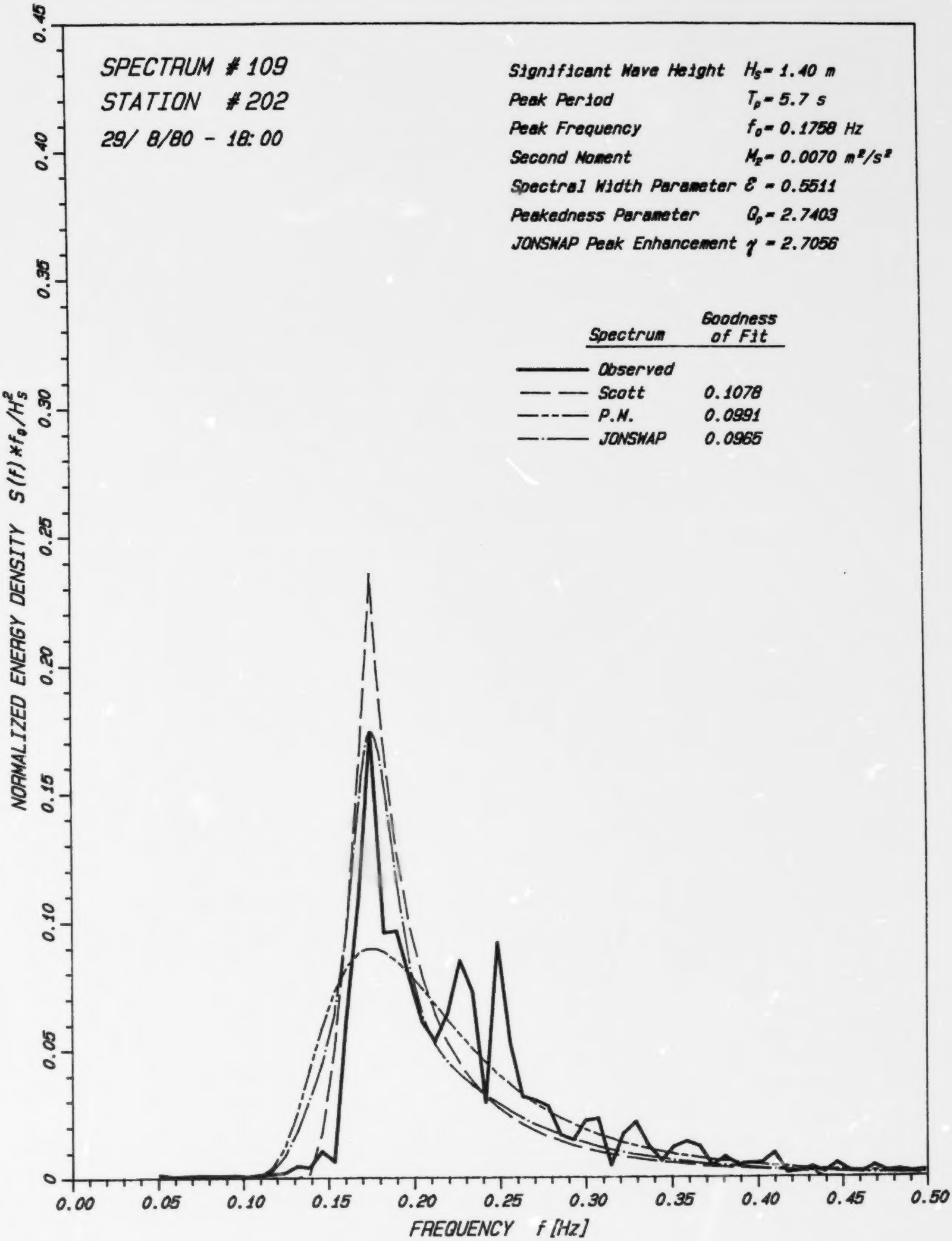

SPECTRUM # 104
STATION # 201
30/ 8/80 - 0: 00
Significant Wave Height H_S = 2.61 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0141 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6734
Peakedness Parameter Q_p = 2.9233
JONSWAP Peak Enhancement γ = 3.7332
Spectrum
Goodness of Fit
Observed
Scott 0.0603
P.M. 0.1172
JONSWAP 0.0852
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

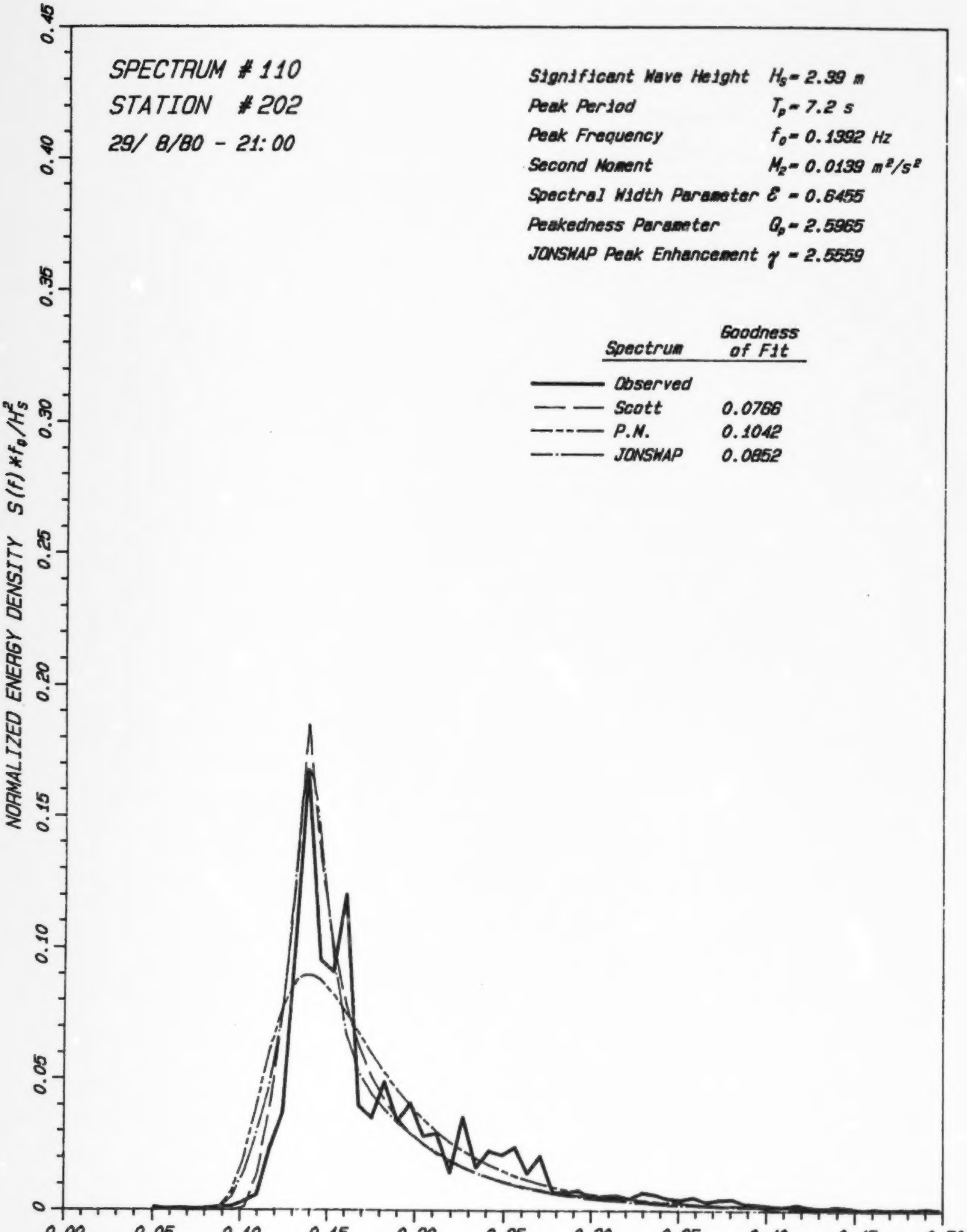

SPECTRUM # 105
STATION # 201
30/ 8/80 - 3:00
Significant Wave Height H_S= 2.95 m
Peak Period T_p= 8.0 s
Peak Frequency f_0= 0.1245 Hz
Second Moment M_2= 0.0154 m²/s²
Spectral Width Parameter ε = 0.6841
Peakedness Parameter Q_p= 2.4150
JONSWAP Peak Enhancement γ = 1.4375
Spectrum
Goodness of Fit
Observed
Scott 0.0839
P.M. 0.0671
JONSWAP 0.0622
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

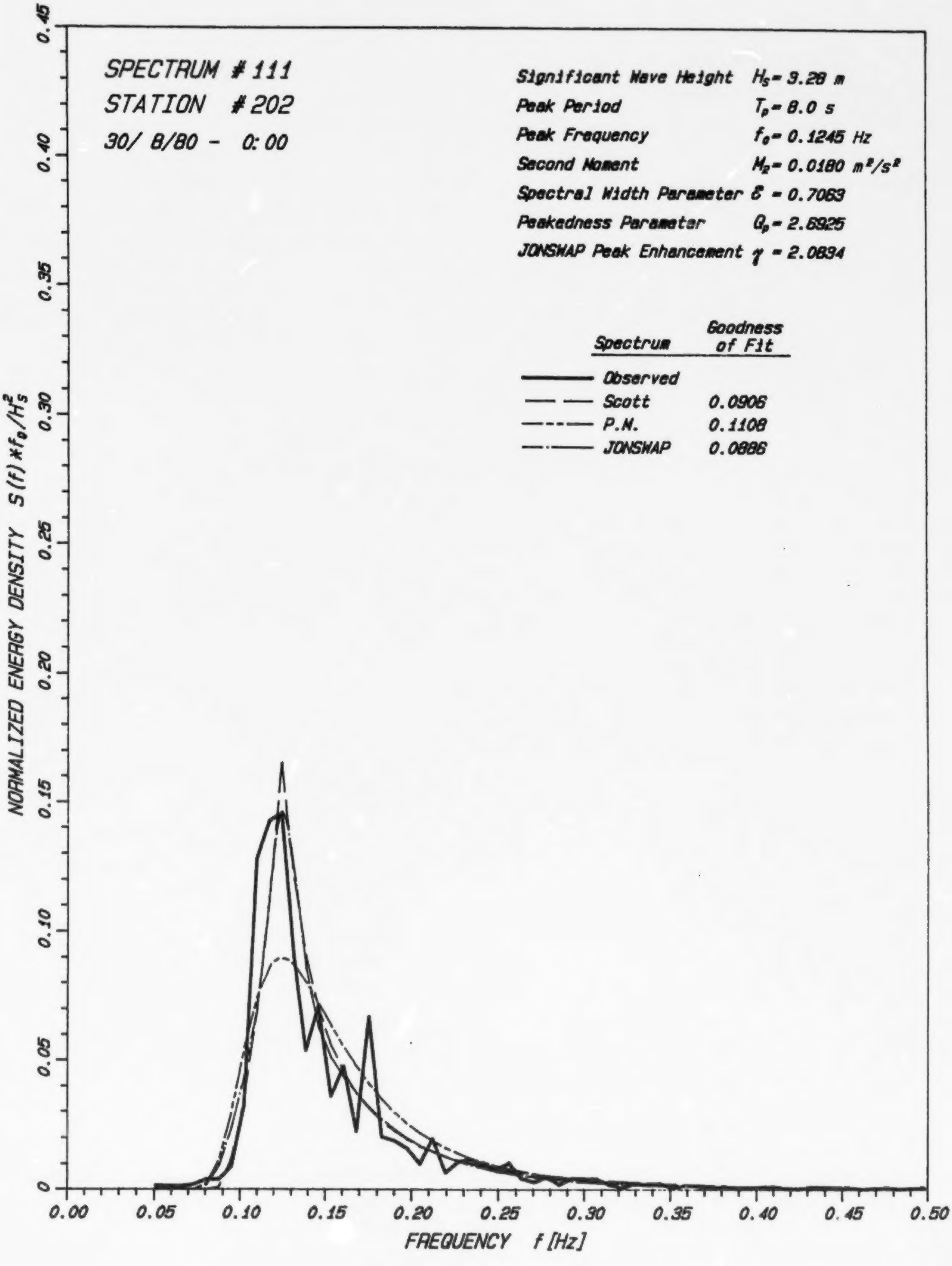

SPECTRUM # 106
STATION # 201
30/ 8/80 - 6:00
Significant Wave Height H_s = 2.66 m
Peak Period T_p = 9.1 s
Peak Frequency f_0 = 0.1099 Hz
Second Moment M_2 = 0.0126 m^2/s^2
Spectral Width Parameter ε = 0.7075
Peakedness Parameter Q_p = 2.1929
JONSWAP Peak Enhancement γ = 1.4630
Spectrum
Goodness of Fit
Observed
Scott 0.0960
P.M. 0.0915
JONSWAP 0.0924
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]

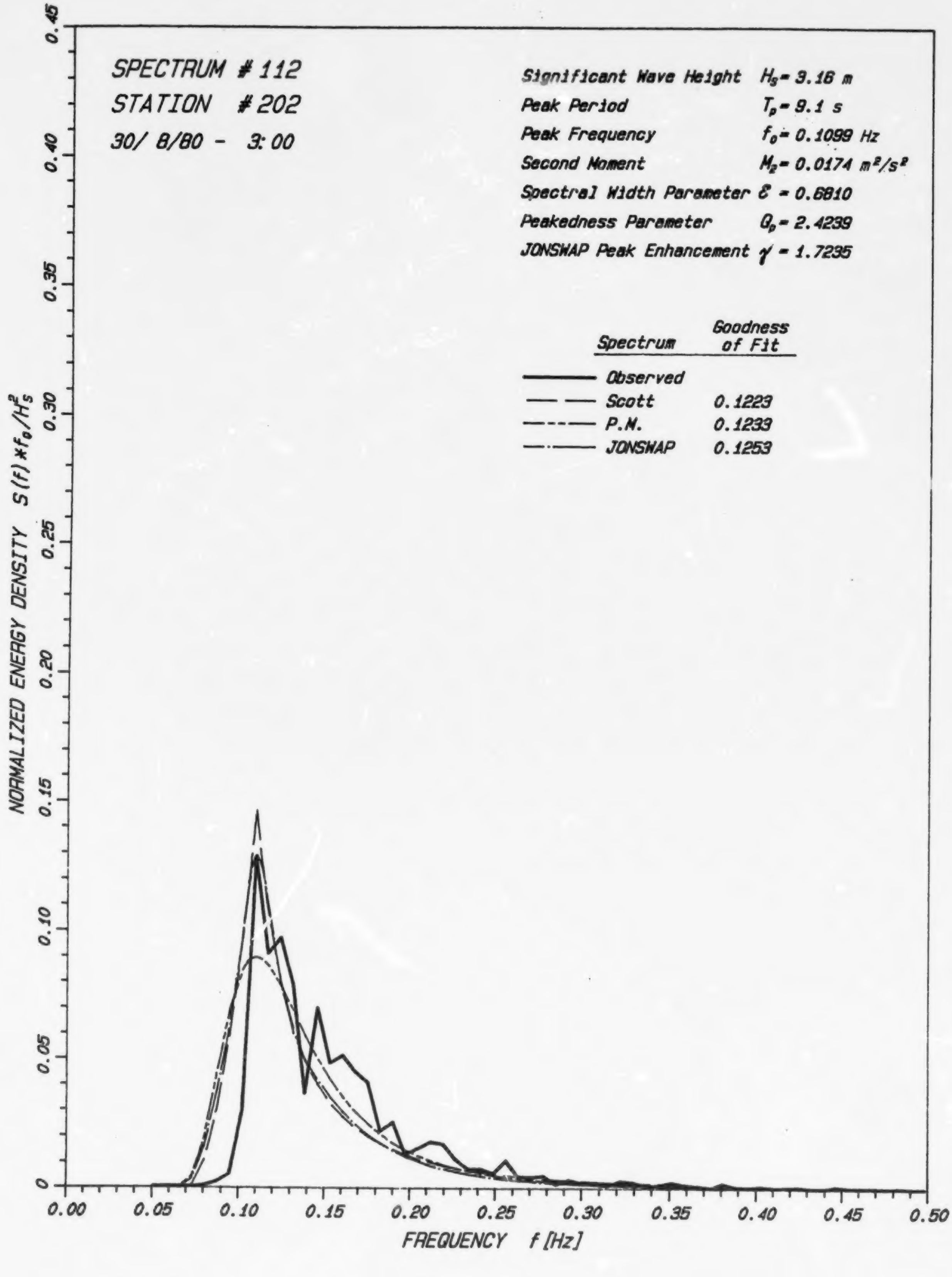

SPECTRUM # 107
STATION # 202
29/ 8/80 - 12: 00
Significant Wave Height H_s= 0.58 m
Peak Period T_p= 3.7 s
Peak Frequency f_0= 0.2710 Hz
Second Moment M_2= 0.0019 m^2/s^2
Spectral Width Parameter ε = 0.4881
Peakedness Parameter Q_p= 2.2013
JONSWAP Peak Enhancement γ = 1.7951
Spectrum
Goodness of Fit
Observed
Scott 0.1788
P.M. 0.0771
JONSWAP 0.0793
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 108
STATION # 202
29/ 8/80 - 15:00
Significant Wave Height H_s= 0.94 m
Peak Period T_p= 4.4 s
Peak Frequency f_0= 0.2270 Hz
Second Moment M_2= 0.0039 m^2/s^2
Spectral Width Parameter ε = 0.5202
Peakedness Parameter Q_p= 2.8326
JONSWAP Peak Enhancement γ = 2.7731
Spectrum
Goodness of Fit
Observed
Scott 0.1474
P.M. 0.0909
JONSWAP 0.0857
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 109
STATION # 202
29/ 8/80 - 18:00
Significant Wave Height H_s = 1.40 m
Peak Period T_p = 5.7 s
Peak Frequency f_0 = 0.1758 Hz
Second Moment M_2 = 0.0070 m²/s²
Spectral Width Parameter ε = 0.5511
Peakedness Parameter Q_p = 2.7403
JONSWAP Peak Enhancement γ = 2.7056
Spectrum
Goodness of Fit
Observed
Scott 0.1078
P.M. 0.0991
JONSWAP 0.0965
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 110
STATION # 202
29/ 8/80 - 21:00
Significant Wave Height H_s = 2.39 m
Peak Period T_p = 7.2 s
Peak Frequency f_0 = 0.1392 Hz
Second Moment M_2 = 0.0139 m^2/s^2
Spectral Width Parameter $\mathcal{E}$ = 0.6455
Peakedness Parameter Q_p = 2.5965
JONSWAP Peak Enhancement γ = 2.5559
Spectrum
Goodness of Fit
Observed
Scott 0.0766
P.M. 0.1042
JONSWAP 0.0852
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 111
STATION # 202
30/ 8/80 - 0: 00
Significant Wave Height H_s = 3.28 m
Peak Period T_p = 8.0 s
Peak Frequency f_0 = 0.1245 Hz
Second Moment M_2 = 0.0180 m^2/s^2
Spectral Width Parameter ε = 0.7063
Peakedness Parameter Q_p = 2.6925
JONSWAP Peak Enhancement γ = 2.0834
Spectrum
Goodness of Fit
Observed
Scott 0.0906
P.M. 0.1108
JONSWAP 0.0886
NORMALIZED ENERGY DENSITY $S(f)*f_0/H_s^2$
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY f [Hz]


SPECTRUM # 112
STATION # 202
30/ 8/80 - 3:00
Significant Wave Height $H_s = 3.16$ m
Peak Period $T_p = 9.1$ s
Peak Frequency $f_o = 0.1099$ Hz
Second Moment $M_2 = 0.0174$ m²/s²
Spectral Width Parameter $\varepsilon = 0.6810$
Peakedness Parameter $Q_p = 2.4239$
JONSWAP Peak Enhancement $\gamma = 1.7235$
Spectrum
Goodness of Fit
Observed
Scott 0.1223
P.M. 0.1233
JONSWAP 0.1253
NORMALIZED ENERGY DENSITY $S(f) * f_o / H_s^2$
0 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
FREQUENCY f [Hz]

APPENDIX II

Specialist Reports

INTRODUCTION

In March 1982 Seaconsult Marine Research Ltd. was contracted to provide Fisheries and Oceans with an evaluation of the representativeness of parametric spectra for sea-state conditions in Canadian waters, and to recommend approaches to presenting spectral climatogical information. Part of this work was conducted by Dr. Sander M. Calisal and Dr. Michael Isaacson, who are recognized specialists in naval architecture and offshore engineering respectively. Their work was condensed into the final project report prepared by Seaconsult.

At the request of Dr. J.R. Wilson of MEDS, these specialists were asked to examine the results of the spectral fitting to measured spectra done by Seaconsult, and to extend their original work to include comment on the results of the parametric spectral representations. In addition they were to recommend additional studies that would resolve, or help to resolve, some of the outstanding issues. Their final reports are presented herein.

USE OF OCEANOGRAPHIC DATA IN THE DESIGN OF FLOATING STRUCTURES AND SHIPS

BY

SANDER M. CALISAL

1. PRESENT USAGE OF SEA SPECTRA

Two major studies, one on the understanding of a probabilistic description of the sea by M. St.Denis and W.J. Pierson (1955) and the other on the motion of ships in regular waves by B.V. Korvin-Krovkovsky and W.R. Jacobs (1957), form the background of ship motion and ship wave load calculations. For a typical ship design the response of the ship to regular sinusoidal waves is either calculated by numerical methods or obtained experimentally in a towing tank in a frequency domain. In some cases, depending on the availability of towing tanks with multiple and directional wavemakers, the kinematic and dynamic responses of the ship in a given sea spectrum can be directly obtained. In most cases, however, the directional spectrum (encounter spectrum) is used in later computational stages after the ship responses in regular seas are available. The expected sea spectra are thus used both for calculation procedures or for the generation of the sea state in towing tanks.

In the design of a ship the exact geographical location and orientation of the ship or her speed cannot be exactly determined. The designer is therefore forced to use nearly all available data on the possible sailing routes of the ship. This requires an extensive collection of sea spectra, which sometimes overwhelms designers. To help designers there exist families of spectra with one or two variables, known as ITTC (International Towing Tank Conference) spectra. The general form of these spectra can be written as:

$$S(\omega) = \frac{A}{\omega^5} e^{-\frac{B}{\omega 4}}$$

where ω is the radian frequency.

This is basically the Pierson-Moskowitz wave spectrum, whose coefficients are:

$$A = 8.1 \times 10^{-3} g \; , \; B = 3.11/h^2_{1/3}$$

(Bhattacharrya, 1978), where g is gravitational acceleration and $h_{1/3}$ is the "significant wave height". Another version of these coefficients is:

$$A = \frac{173 h^2_{1/3}}{T_1^4} \; , \; B = \frac{691}{T_1^4}$$

where T_1 is the average period observed (in seconds) defined by m_o/m_1, where m_o, m_1 are the first two spectral moments. When no other data are availabe and only the wind speed is known, ITTC gives the relationship between wind speed and the corresponding value of significant wave height required in the above formula.

To transform the above spectrum into a directional spectrum, a cosine power-spreading function of the form

$$S(\omega,\mu) = \frac{2}{\pi} \cos^2 (\mu) \; S(\omega)$$

is recommended by ITTC. The ITTC spectra are continuous and have no "enhancement" factor such as exists in other well-known spectra as, for example, the Joint North Sea Wave Project Spectrum (JONSWAP).

The field of naval architecture is now well aware that there might be multiple "enhancement" frequencies or local peaks and multiple storm directions for point spectra. The numerical design methods developed so far are flexible enough to use any such sea spectra; therefore, the availability and correct definition of the spectra is of great concern to naval architects.

The last important step in the design is to assess the dynamic effects of ship motion. In these calculations the critical value is either the duration of the storm, the existence of a specified spectrum for a given length of time, or wave persistence and duration. Wave persistence and duration data are usually not available explicitly; therefore, a value assumed to be conservative and reliable is adopted for design purposes.

2. STEPS IN DYNAMIC RESPONSE CALCULATIONS

The prediction of ship dynamic response is done as follows. The appropriate "wave spectrum" is converted into an "encountered wave spectrum", as the average motion of the ship will change the frequency affecting the ship. The encountered wave spectrum is then multiplied by the frequency dependent ship response amplitude operators which are independent of the wave spectrum in linear formulations and depend mainly on the ship geometry and ship speed. The resulting spectrum is called the "response spectrum". This spectrum is then analysed statistically and statistical measures such as average response and most probable largest value are calculated in terms of the properties of the area under the response spectrum.

An experienced naval architect will normally design a ship to have a low response amplitude operator at the peak encounter spectrum, i.e. that the ship "resonant" frequency will be outside of the high energy zone in the encountered wave spectrum. If possible, that frequency will be lower than the low cut-off frequency of the encountered wave spectrum. In some cases, where the ship or a component of a ship has a relatively high resonant frequency, the amount of energy in the high frequency range of the wave spectrum becomes important. This portion of the wave spectrum is usually called the "tail" region.

In view of the above procedure, a proper definition of a wave spectrum by parametric curves or otherwise should

1. Give correctly the amount of total energy in the spectrum (or the related quantity i.e. the significant wave height);
2. Locate the peak frequency and the distribution of energy at different frequencies with minimum error;
3. Describe effectively the amount of energy at the tail end of the spectrum and;
4. Estimate the low cut-off frequency in such a way that no significant energy is "available" below that frequency. The visual inspection of the fitted curves is then done in accordance with the four criteria given above.

3. SHORTCOMINGS OF CURRENT METHODS AND OF OCEANOGRAPHIC DATA

As more data are collected in the ocean and the general oceanographic knowledge expands the restricted nature of the ITTC spectrum becomes increasingly obvious. As a result, work on spectral families representing ocean waves in certain locations more precisely is being done. In addition to this work, new types of platforms have been built and operated for a variety of purposes. These developments have brought about a need to know the oceans with more accuracy and also a need to be able to forecast what type of spectra might be encountered during the lifespan of a platform. Naval architects are now concerned about the availability of realistic types of spectra and the range of their parameters for platform designs. Such data are not always present for all regions of the oceans.

In addition the method of superposition is constantly critisized. Naval architects are now interested in time domain studies as well as in frequency domain studies. In time domain calculations a "severe wave", either recorded or calculated, is used to obtain the responses of the ship and the resulting dynamic quantities. The information available on such waves is limited, if not unavailable, for most navigated areas.

An additional area of concern to naval architects is the range of application of information obtained exclusively from a point spectrum. Complementary information seems to be necessary for the calculation of sea loads on long ships. For example, a cross-spectrum of waves at different locations appears to be desirable in order to increase the accuracy of load calculations relevant to large structures (McCormick 1979).

4. POSSIBLE FORMAT FOR OCEANOGRAPHIC DATA

There are several methods for the presentation of oceanographic data. One method that is attractive is the development of an atlas of wave and wind environments by geographical areas and seasons. This atlas should provide environmental data for translating seakeeping performance requirements in specified operating areas and seasons into specific design criteria. The following oceanographic data for various locations would be appropriate:

1. Wind speed and direction.
2. Wave spectral data for multipled directions (15 frequency bands and 12 directions seem to be the established standard (Lewis, 1979):

   a. Significant height;
   b. Characteristic period(s), peak period and other parameters of the spectrum, if any;
   c. Primary and secondary directions;
   d. Spectral width, and the definition of spectrum "tail" regions;
   e. Angular spread.

3. Statistical data on wave steepness and wave persistence and duration.
4. The most severe wave, based on wave height and steepness as recorded.
5. Cross-spectrum, if possible.

The ideal format within the present technology would be a printed atlas where the minimum number of statistical parameters listed above can be accessed by designers. A general family of spectra related to these statistical parameters, such as the ITTC spectrum presented earlier, would be most relevant. However, the remainder of the data for spectral definitions by frequency bands and the time domain description of a severe wave should be available in a format directly compatible with mainframe and/or desktop computers. A tape, cassette or diskette medium is suggested. As most of the calculations for ship motion or loads can only be done efficiently with the help of a computer, this computer-compatible format would be the most efficient method and would reduce input-output errors while facilitating improvements and updating. Such a computer format would be equally useful in the generation of waves in a towing tank. As most modern wavemakers are controlled by computers, the extensive data referred to above can be easily coupled to these wavemakers. A naval architect with the above set of information available can generate an encounter spectrum, compute the dynamic response of a ship, and generate the relevant statistical quantities.

5. VISUAL INSPECTION OF THE SPECTRAL FITTING IN "WAVE SPECTRA IN CANADIAN WATERS"

One hundred and twelve spectra analyzed for spectral fitting corresponding to six locations in Canada have been visually inspected from an application point of view. The following general comments can be made. The peak spectral values are seen to be best represented by JONSWAP formulations. The correlation between the parametric representation and the observed spectra seem to increase with the significant wave height of the spectra. Spectra with low significant wave height seem to have oscillations or multiple peaks. Some spectra (spectra 101, 107 and others) are observed to contain energy at frequencies below the lower cut-off frequency of the parametric spectra. From an application standpoint multiple peaks and energy below the cut-off frequency are of interest, as they might change the response spectra of a ship by a significant amount.

One can conjecture that some of these irregularities are due to the transient nature of the records or to the noise in in the data. As the response of ships at each frequency is calculated for a steady state sinusoidal wave any presence of transient waves in a spectrum should be treated with additional care. As boats and ships are subject to low energy spectra most of the time, it is important to know if these deviations from the parametric definition of spectra have physical significance or if they are due to some experimental or numerical error.

The spectra presented belong basically to five different location in Canada. Comments on each group of numerically computed spectral fittings and observed spectra are given below. In this visual inspection attention is given to the following features of the spectra:

1. The location of peak frequency.
2. General distribution of energy in the frequency domain.
3. Definition of the "tail" or high frequency end of the spectra.
4. Discrepancies between observed and fitted spectra, such as multiple peaks, oscillations, etcetera.

5.1 Spectra for Station 60 (Lake Ontario)

Spectra related to station 60 which have a significant wave height larger than 2.5 m, are well represented in the engineering sense by the JONSWAP formula. Parametric representation such as this can be successfully used for ship motion and related dynamic calcuations. For fatigue related calculations the Pierson-Moskowitz spectrum (P.M.) on the other hand, seems to offer a conservative estimate for most of the spectra. The low frequency waves in spectrum 13 are not represented by any parametric spectra.

5.2 Spectra from Station 103 (Tofino)

Parametric representationsare successful where the significant wave height is larger than 5 meters. On the high frequency side of the spectrum JONSWAP underpredicts the energy in the observed spectra. Except for spectra 19 and 24, energy density values at frequencies higher than the peak frequencies remain below the values given by P.M. spectra. Spectra 24, 25 suggest that additional energy exists below the lower cut-off frequencies. Additionally multiple peaks and oscillations exists in some of the observed spectra.

5.3 Spectra from Station 138 (Davis Strait)

Probably the best representation by JONSWAP spectra is spectrum 49 in this group. Multiple spikes in spectra 39, 42, 43, 60, 61 are disturbing from an application point of view, as their physical meaning is not clear. In most cases P.M. spectra give a conservative estimate at the higher frequency ride.

5.4 Spectra from Station 140 (Hibernia)

Spectrum 67 exhibits a relatively large peak at a frequency lower than peak frequency and the spectrum 66 shows a peak at higher frequencies. Probably the best fit in this group of spectra is spectrum 69, which has a significant wave height of 5.02m. Spectra 73, 76, 78, 83, 87 and others, on the other hand, show a poor fit and have multiple spikes, even though they have a significant wave height higher than 5m, which is contrary to the trend observed in the earlier spectral fittings.

5.5 Spectra from Stations 201 and 202 (Beaufort Sea)

Spectra 101 and 107 show energy at frequencies smaller than the lower cut-off frequency. These spectra have a relatively small significant wave height. The spectral fitting is observed to improve as the significant wave height of the spectrum increases. Again, as in the previous cases, the P.M. spectra better represents the tail end of the spectrum.

6. CONCLUSIONS AND RECOMMENDATIONS

In view of the above observations the effect of the application of curve fitted spectra for engineering purposes can be estimated as follows:

1. Dynamic calculations

For those calculations that include dynamic stress and ship dynamic stability calculations the major contribution to the calculated dynamic quantities will come from the peak energy frequency zone. The calculated JONSWAP spectra seem to offer a better definition of the sea in this range. It might be suggested, however, that such calculations be limited to spectra with significant wave height above a certain value. As observed previously, this value of significant wave height changes with the observation station. For most naval architecture applications, excluding small boats, a spectrum with relatively high significant wave height is of interest. Therefore, computed spectral parameters are valuable for large ship applications in relatively large storms.

The energy that exists in the observed spectra but is not represented by the fitted spectral curves is of some concern because its effect might be significant for most applications, especially at lower frequencies. Some of these spectra were referred to earlier and seem not to be limited to one particular observation point. The dynamic response for some typical ships such as fishing vessels, supply vessels, tankers, etcetera, calculated separately in observed spectra and in fitted spectra, can give a quantitative comparison of their effect on engineering calculations. This is surely a better way of assessing the applicational impact of spectral fitting and is highly recommended.

2. Higher frequency and fatigue calculations.

The present spectral fitting does not seem to be adequate for high frequency calculations, mainly because of oscillations seen in the observed spectra. Also the JONSWAP spectra which seem to represent the peak energy region rather well underestimate the energy in these higher frequencies. To use the available information, however, the P.M. spectra can be taken as an upper limit. In view of the error analysis given on page 36 of the main report, this might be a more reliable calculation than straightforward application of the observed spectra. Additional fundamental research and work are needed in the definition of this portion of spectrum.

For reliable engineering applications of the observed and fitted spectra the following additional studies are recommended:

1. Explanation of the origin of oscillations on the observed spectra, and estimation of the transient component of the sea spectra.
2. Spectral fittings with a larger number of spectral parameters, allowing for better definition of the tail section of the spectra.
3. Application to standard ships of the observed and fitted spectra in order to study the error in the dynamic spectra.

4. Correlation of the spectral parameters to meteorological data. This is a very important step as waves and winds usually affect the ship together. Knowledge of storm duration is necessary for the proper calculation of dynamic quantities in the probabilistic sense.
5. Improved parametric fittings for spectra with relatively low significant wave height. Such work will be very useful for dynamic studies relevant to small ships such as fishing vessels, supply ships and pleasure craft. The present spectral fitting does not seem to be successful for such applications.

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DESIGN REQUIREMENTS OF WAVE DATA PRODUCTS

BY

MICHAEL ISAACSON, P. ENG.

1. OBJECTIVES

To propose improvements in the detail of wave data products available from instrument recordings in order to satisfy more closely offshore and coastal engineering design requirments. Emphasis is to be given to the structural design of offshore structures.

To comment on the engineering implications of the spectral fitting described in the main report "Wave Spectra in Canadian Waters".

2. INTRODUCTION

Information on ocean wave characteristics is required for a variety of offshore or coastal engineering design situations. Some of the categories of offshore structure include jacket platforms, gravity platforms, mobile drilling rigs including semi-submersible and jack-up platforms, compliant platforms including the tension leg platforms and the guyed tower, mooring systems, submarine pipelines, caissons, and various coastal structures including piles, breakwaters, seawalls and artifical islands. (Ships and ship-like marine vessels are considered in detail by Sander M. Calisal in this report.)

Design criteria for offshore structures generally include survivial criteria, which may be set by regulatory authorities to whose requirements a rig is designed, and operational criteria, which may be set by a rig's owners or operators. The various criteria may relate to stresses in the structural members, tensions in the mooring system, the effects of environmental loads - including those due to wind, waves, currents, ice and earthquakes - on the integrity, foundations or motions of the structure.

The design procedure with respect to fluid loading may include some or all of the following components:

- static and dynamic analyses of the structure for extreme loading conditions,
- intact and damaged stability analysis,
- a motion response analysis for operational, survival and intermediate conditions,
- a fatigue analysis,
- a mooring analysis.

In coastal engineering projects, other factors may assume particular importance. These may include the effects of breaking waves on a coastal structure, an assessment of short-or long-term sedimentation or erosion patterns, and the degree of wave protection provided by a harbour.

In the most general sense, the offshore platform design engineer is required to consider two categories of hydrodynamic forces. The first relates to extreme condition forces associated with rare "design" storms which may result in immediate structural or foundation failure. A series of several "design" storms may need to be considered to establish the extreme condition forces. The second force category concerns nominal condition forces associated with commonly encountered storms many times during the structure's life-time. These affect the fatigue life of a structure or its down-time.

There are two distinct approaches whereby one can follow the above procedures. One is a deterministic approach, which itself may be either pseudo-static or time-dependent, and the second is a stochastic approach. In the deterministic pseudo-static method, which is the simplest to use, maximum loads are calculated and applied to a static analysis of the structure, whereas in the deterministic time-dependent method, a time record of the free surface elevation is used to calculate time-dependent loads, taking into account the dynamic response of the structure. The deterministic approach can generally take nonlinearities into account and is more appropriate for extreme loading conditions. The stochastic approach, in which the loading and response are generally linearized is more appropriate for nominal conditions. In the stochastic approach the wave motion is treated as a random process and is described by its spectral density. A corresponding description of the loads on, and response of, the structure is obtained. Thus, in the stochastic approach all calculations are carried out in the frequency domain, whereas in the deterministic approach they are carried out in the time domain. The different approaches outlined above have been described by Bea and Lai (1978). An indication of the various concepts and procedures to be followed in wave loading calculations is given by Sarpkaya and Isaacson (1981).

3. WAVE DATA REQUIREMENTS

3.1 Importance of Existing Data Products

In many cases design limitations may be due to the restricted amount of wave data available for a particular site rather than to the quality of the data or to its manner of presentation. Or they may be due to shortcomings in the state-of-the-art resulting in an inability to utilize more detailed wave data products. For example, in some situations only a one-dimensional wave spectrum may be used even though a directional wave spectrum is available. Consequently any improvements to the detail of wave data provided should be in addition to, rather than in place of, the more basic wave data products which are presently available. Thus in the above example a one-dimensional wave spectrum should always be provided even when a directional wave spectrum is also given.

3.2 Directional Wave Spectra

The directional spreading of waves is often neglected in offshore design, either to simplify the design procedure, or because of one's inability to properly account for the spreading, or because of insufficient environmental data. In the uni-directional approach, all wave activity is considered to be concentrated in the most unfavorable direction and a conservative estimate of the structural loading or response is then obtained.

Offshore design is now being extended to account for the effects of directional spreading (i.e. Sharma and Dean 1979, Huntington 1979), and information on directional spectra is increasingly required by the designer. At the same time, directional wave spectra obtained from instrumental measurements are becoming more widely available.

A complete directional spectrum may be presented in a variety of tabular or graphical forms, some of which have been mentioned in the main report. One preferred format is a plot showing the directional spreading function $G(f,\theta)$ vs. θ for a series of frequencies f. However, such complete representations of a directional spectrum for each recording period become extremely unwieldy for general design use, and thus it is important that simple parametric fitting be applied to each available spectrum. The most appropriate parametric form appears to be the cosine-power representation in which $G(f, \theta)$ is writtern as:

$$G(f,\theta) = C(s)\cos^{2s}\left[\tfrac{1}{2}(\theta-\bar{\theta})\right]$$

(adopted, for example, by Dean 1977), or

$$G(f,\theta) = \begin{cases} C'(s)\cos^{2s}(\theta-\bar{\theta}) & \text{for } \theta-\bar{\theta} < \pi/2 \\ 0 & \text{otherwise} \end{cases}$$

(adopted by Borgman 1969). $\bar{\theta}$ is the mean wave direction, s is a spreading parameter and the normalizing function C(s) or C'(s) may be expressed explicitly in terms of s. The parameter s depends on frequency f and its dependence on f may be tabulated. As a further simplification, the directional spreading function may be taken as independent of frequency and the frequency-independent value of s thereby provided.

In this way it would be relatively straightforward to extend the existing one-dimensional spectrum tabulations for each recording period to include the mean wave direction $\bar{\theta}$ and the frequency-independent spreading parameter s. As a further extension, frequency dependent values of s may be provided in a separate tabulation.

3.3 Mean Wave Direction

The mean wave direction $\bar{\theta}$ has been mentioned above as being provided by a directional wave spectrum. The long-term variation of mean wave direction is particularly important in many engineering situations. Applications include wave transformation due to refraction, littoral drift estimation, wave diffraction into harbours, and structural loading or response which is sensitive to wave direction.

In addition to the tabulation of $\bar{\theta}$ mentioned in Section 3.2 above, $\bar{\theta}$ may also be presented in an analogous way to a scatter diagram or to a significant wave height vs. time plot. An extended scatter diagram showing the number of occurences of various combinations of significant wave height, peak period as well as mean wave direction has been suggested (i.e. Tickell 1979), and would be especially useful in improving structural design with respect to long-term wave loading.

3.4 Wave Groups

Wave group characteristics are important in several ocean engineering situations including long period excursions of moored vessels associated with wave drift forces, vessel capsizing and wave action on breakwaters. Although considerable advances have been made in the last few years, further progress is still required to enable design techniques to exploit wave group descriptions that may be available.

One important wave data product used in drift force calculations (i.e. Clauss and Schellin 1982) is the "wave group spectrum" $S_G(\mu)$ defined as:

$$S_G(\mu) = 8 \int_0^\infty S\ (\omega)\ S\ (\omega+\mu\ )\ dw$$

where $S(\omega)$ is the one-dimensional wave spectrum. The run length is a further parameter used to describe wave groups and may be presented as a plot or a tabulation indicating run length duration vs. envelope level exceeded.

3.4 Coexisting Currents

It is now recognized that coexisting currents play an important role in affecting the wave loads on fixed offshore structures, and the simultaneous measurement of wave and current data is increasingly required. Whenever such data can be gathered, an indication of the current magnitude and direction for each recording period is required. This can be provided as a simple extension to the tabulations of one-dimensional spectra. (The location of measurement point below the water surface would be separately specified.)

4. COMMENTS ON SPECTRAL FITTING

4.1 Summary of Report on Spectral Fitting

The main report "Wave Spectra in Canadian Waters" compares a series of measured one-dimensional spectra obtained in Canadian waters with three parametric spectra. These are the two-parameter Pierson Moskowitz spectrum (corresponding in form also to the Bretschneider, ITTC and ISSC spectra), the (two-parameter) Scott spectrum and the (three-parameter) JONSWAP spectrum. The spectra are fitted by matching significant wave height, peak frequency, and in the case of the JONSWAP spectrum also the magnitude of the spectral peak. Because of the three parameter fitting, the JONSWAP spectrum provides the best fit to the measured spectra, although the peak enhancement factor γ exhibits considerable scatter. As might be expected, the Pierson-Moskowitz spectrum generally underpredicts the magnitude of the spectral peak and overpredicts the spectral density on either side of the peak.

4.2 Implications for Offshore Design

In the dynamic response of an offshore structure due to wave loading, any frequency range of the wave spectrum may assume particular importance, depending on the peak frequency in relation to the resonance characteristics of the structure. From the spectral fitting carried out, it appears that the Pierson-Moskowitz spectrum tends to overpredict the energy in the high frequency tail but to underpredict the magnitude of the spectral peak. Both the Scott and the JONSWAP spectra represent both these features reasonably well.

In fatigue calculations, the high frequency tail of the spectra for more extreme storms, as well as the spectral peak for more common storms may become important. In other situations the tail of the spectrum for more nominal storms may be important. Fatigue damage or failure is due to the cumulative effect of a combination of storms comprising a greater number of less intense storms and fewer more extreme storms. Consequently the Pierson-Moskowitz spectrum may either under- or overpredict fatigue damage in the general case and specific calculations are required to illustrate the effect for different test situations. No general conclusion may be reached regarding the reliability of the Pierson-Moskowitz spectrum in fatigue calculations.

The low frequency range of the spectrum is generally important for compliant or large floating structures with low natural frequencies or for the surge response of moored floating structures (which have a low surge natural frequency). Of the three spectra examined, the Scott spectrum has a sharp low frequency cut-off and sometimes underpredicts the low frequency energy in a spectrum. However, this distinction is not consistent enough to provide any meaningful conclusion concerning the suitability of one or other spectrum with respect to low frequency response.

In a motion response analysis of a floating structure, a series of design spectra covering a range of peak frequencies f_o, with appropriate significant wave heights for each f_o, are generally applied. This procedure provides a curve (as in Figure 1) showing the maximum motion expected for different

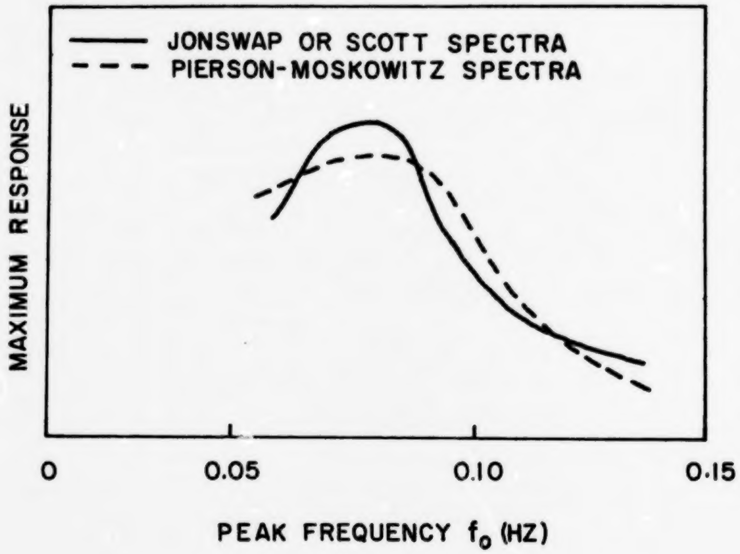

Figure 1: Typical curves of maximum response vs. peak frequency of design spectra based on different parametric spectra.

possible design spectra characterised by f_o , and this in turn provides an estimate of the maximum possible motion. The Pierson-Moskowitz spectrum generally has a lower spectral peak and a greater band-width than do the Scott and JONSWAP spectra. This will typically result in differences as indicated in Figure 1. In such cases the Pierson-Moskowitz spectra will tend to underpredict maximum design motions.

5. RECOMMENDATIONS

The following recommendations can be made:

1. It is important that any improvement to the detail of wave data provided does not replace the more basic data products which are presently available.
2. A complete description of a directional wave spectrum for each recording period is likely to prove too unwieldy for general design use. Information on the spreading parameter, either as a frequency independent quantity or as a function of frequency is most suitable.
3. Information on mean wave direction for each recording period is useful in many offshore or coastal engineering applications. This may be tabulated alongside one-dimensional spectra data. In addition, an extended scatter diagram (showing number of occurrences of different combinations of height, period and direction) is required.
4. Further extensions to the detail of wave data provided should deal with a description of wave grouping or of coexisting currents.
5. The spectral fitting carried out indicates that the Pierson-Moskowitz spectrum generally underpredicts

the spectral peak and has a relatively wide band-width. The effect of this on fatigue calculations is not presently understood and further studies are recommended to quantify any important differences in estimated fatigue life.

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